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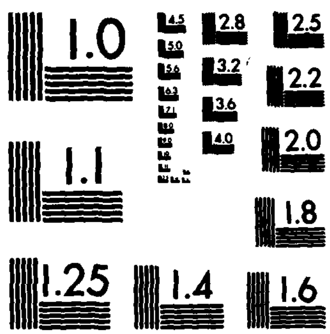

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A Study of Solvent and Aqueous Cleaning of Fluxes

by
Donna Sanger
and
Kathryn Johnson
Engineering Department

FEBRUARY 1983

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

Naval Weapons Center

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FOREWORD

The research described in this report was completed on 7 January 1983 and is a Naval Weapons Center (NWC) Independent Exploratory Development project, program element 62766N/ZF66-512. It is part of an effort to test the effectiveness of existing cleaning techniques used in the production of high reliability printed wiring assemblies. This final report presents the advantages and disadvantages of rosin and non-rosin fluxes.

This report has been reviewed for technical accuracy by Edwin B. Royce.

Approved by
D. J. RUSSELL, *Head*
Engineering Department
11 February 1983

Under authority of
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Capt., U.S. Navy
Commander

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(U) *A Study of Solvent and Aqueous Cleaning of Fluxes*, by Donna Sanger and Kathryn Johnson. China Lake, Calif., Naval Weapons Center, February 1983. 108 pp. (NWC TP 6427, publication UNCLASSIFIED.)

(U) An independent exploratory development (IED) study was undertaken by the Soldering Technology Branch, Code 3681, of the Naval Weapons Center, China Lake, Calif., to develop data on solvent and aqueous cleaning.

(U) Rosin-based and non-rosin fluxes were tested for ionic cleanliness after processing in one of three systems: solvent vapor degreasing, in-line aqueous cleaning, or a combination of solvent vapor degreasing followed by a deionized water rinse. Solvents containing a large percentage of alcohol gave the best ionic cleanliness for even the most difficult to remove rosin-based fluxes. Water alone cannot remove non-rosin flux residue. Detergents removed ionic contamination from the rosin, mildly activated (RMA) and the non-rosin fluxes but were unable to clean rosin, activated (RA) fluxes to an acceptable level of cleanliness. Combination cleaning proved very effective for removal of rosin-based fluxes.

(U) Insulation resistance testing of detergent cleaned rosin-based fluxes showed no degradation of sample printed wiring board resistance characteristics. Non-rosin fluxes degraded board resistance to an unacceptable degree.

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ACKNOWLEDGEMENT

We wish to express appreciation to the flux, solvent, and detergent manufacturers for their cooperation in these tests. This study could not concentrate on products from one or two flux manufacturers or one flux and detergent from seven or eight manufacturers. If any product was eliminated from a particular sequence or not exposed to unique process conditions it was because of schedule constraints. The Soldering Technology Branch does not qualify fluxes but is concerned with the process controls associated with fluxes and cleaning of flux residues.

The personnel from the Branch who participated in this effort included:

Jim Raby, Soldering Technology Branch Head
Donna Sanger, Chemist
Kathi Johnson, Chemist
Bill Vuono, Chemist
Rick Breitengross, Chemical Technician
Carl Buchanan, Physicist, former NWC employee
Richard Maxwell, Technician, former NWC employee

I. INTRODUCTION

The fabrication of electronic assemblies for the Department of Defense has primarily been accomplished by soldering with rosin fluxes per MIL-F-14256 and cleaning with chlorinated/fluorinated solvents or alcohols. Due to the Environmental Protection Agency (EPA) and the state regulations to control the disposal of the solvents, coupled with the petroleum-based solvents' cost fluctuation, industry is exploring water soluble type fluxes and water cleaning systems.

The cleanliness of printed wiring assemblies is an important aspect in the reliable functioning of military hardware. Many studies have been conducted by both military and industry to determine the level of cleanliness that is required for proper functioning. Thus far, cleanliness levels have been established for only ionic contamination.

This study began by evaluating how effective the MIL-P-28809 solvent extract test method was for determining printed wiring board cleanliness. It has evolved into a thorough investigation of both rosin and non-rosin fluxes and both aqueous and solvent cleaning.

An extensive testing program involving thirty-six fluxes, four detergents, seven solvents, and four years of manpower was conducted in an effort to determine which fluxes could be removed to an acceptable level from the sample boards.

Cleanliness was also checked by insulation resistance testing of samples that had passed ionic cleanliness tests. Some effects from non-ionic contamination were detected by this test method.

Solderability of the fluxes was also examined in an effort to correlate the cleaning ability of a flux to its expected performance.

This report is organized into six sections: baseline properties of the fluxes including chloride content, specific gravity, pH, and solderability; processing procedures that describe sample preparation and the equipment that was used; solvent testing of Rosin, Mildly Activated (RMA) and Rosin, Activated (RA) fluxes; aqueous cleaning of RMA, RA, and non-rosin fluxes; combination cleaning involving solvent cleaning followed by a deionized water rinse; and insulation resistance testing using a modified version of the MIL-STD-202, Method 106E Moisture/Temperature cycling.

The fluxes included in this study were classified according to the MIL-F-14256 Qualified Products List criteria. The military uses this specification for the purchasing of fluxes used on military hardware. There are three classes that were examined in this study: RMA, RA, and non-rosin. An RMA flux, according to MIL-F-14256 is one that contains a small amount of a non-halide activator. An RA flux, accoring to MIL-F-14256, can contain a small amount of a halide activator. The non-rosin fluxes are not classified by the military. This group encompasses a wide variety of water soluble, water removable, organic acid, and modified resin fluxes. The generic name, non-rosin, can describe all of these flux types.

The fluxes were divided into the three catagories and are listed below.

RMA	Alpha 611F
	Gardiner 1235
	Kester 197
	Amco No. 8
	Lonco MIL-A-35-DA
	Cobar 210-35
	Kenco 365
	Alpha 620F

RA	Lonco 106-A-35X-MIL*
	Kester 1585-MIL
	Alpha 711
	Kenco 465-MIL
	Fry R-8-20
	Kenco 413
	Gardiner 2625
	Kester 1585
Non-rosin	Fry 600
	Kester 2300
	Kester 2154
	Kester 2330
	Kenco 183
	Lonco 3355-11
	Lonco 35-WS
	Alpha 709
	Alpha 850-33
	Cobar 353
	Gardiner 5425
	Gardiner 5830
	Kester 2331
	Kenco 192
	Amco 220-35
	Superior No. 30
	Superior No. 45
	Xersin 2015
	Multicore ESF 30
	Multicore ESS 33

*Lonco 106-A-35X-MIL was reclassified to an RMA flux during the course of the study but for consistency its original classification was retained.

II. BASELINE PROPERTIES

In order to establish baseline properties for comparison of fluxes with later testing, as well as comparison between flux types, the following tests were conducted: specific gravity, pH, percent solids, halide cont[illegible]t by three methods, flux carrier identification, and solderability comparison.

SPECIFIC GRAVITY

The specific gravity of each flux was determined by hydrometer. Figure II-1 lists the specific gravity measured, the temperature at which it was recorded, and the manufacturers' recommended value.

pH

The [illegible] of the fluxes was determined by taking a 100 ml sample of raw flux and measuring with a Beckman 6100 temperature compensated pH meter. The meter was standardized with buffer solutions before the measurement was recorded. The pH values are listed in Figure II-2.

PERCENT SOLIDS

The percent solids of each flux was determined by evaporation of the solvent in a vacuum oven until a constant sample weight was found. The values for percent solids are found in Figure II-3.

HALIDE CONTENT

Halide content was determined by three methods. The Beilstein test and the silver chromate paper test were investigated for their use as quick and easy tests for halide content. A silver nitrate titration was used for a more quantitative determination of halide content.

BEILSTEIN TEST

A copper wire was dipped into the flux and then burned to dryness with a propane torch. A green colored flame indicated that a h lide was present. The intensity of the green color was operator dependent so the results were confirmed with the silver chromate paper and silver nitrate titration tests. The results are listed in Figure II-4.

SILVER CHROMATE PAPER TEST

The silver chromate paper test was used as another rough indication of halide content. The sensitivity of the silver chromate paper was determined to identify the detection limits of the test. Solutions of varying known concentrations of NaCl were prepared and tested for the paper color change, results for this test listed below show the paper is sensitive enough to detect 0.0625% halide.

NaCl Solution Concentration	Color Change
1.0%	Grey
0.5%	Grey
0.25%	Grey
0.125%	Grey
0.0625%	Slight grey
Blank	No change

A drop of raw flux was placed on a square of silver chromate paper. The paper was immersed in isopropanol and then placed on absorbent paper to dry for 10 minutes. A positive test for halide was indicated by a white, grey or yellow circle of residue. A white color indicated more halide than a grey circle, while a yellow circle specifically indicated a bromide. The results of the silver chromate paper test confirmed the results of the Beilstein test and are listed in Figure II-5.

SILVER NITRATE TITRATION

The silver nitrate ($AgNO_3$) titration was used to quantify the halide content of the fluxes. An ether/deionized water separation was performed on the rosin-based fluxes followed by a standard silver nitrate titration of the water extract. Non-rosin based fluxes were neutralized to a pH of 7 using sodium bicarbonate ($NaHCO_3$), and then titrated with silver nitrate. Results were calculated as percentage of chloride and are listed in Figure II-6.

FLUX CARRIER IDENTIFICATION

The flux carriers were identified by Nuclear Magnetic Resonance (NMR) so that if the specific gravity needed to be adjusted the correct alcohol for each flux would be known. These results are listed in Figure II-7.

SOLDERABILITY

Several attempts were made at establishing a comparison of fluxes based on their relative solderabilities. The problem was not in generating the data, but in interpreting it because there is no acceptance

criteria for solderability of a flux. A Multicore Universal Solderability Tester in the wetting balance mode was used in conjunction with a Hewlett-Packard 8500 computer hookup.

Copper tabs were selected as sample coupons. All coupons were cut to the same size and cleaned on the day of the test. A four-stage cleaning process was used. The coupons were agitated for 90 seconds in each of these four stages. The process was a mild detergent solution followed by a deionized water rinse, then an ammonium persulfate solution with another deionized water rinse. The coupons were then dried with compressed air and stored in a zip lock bag.

The solder bath temperature was set at 235°C. The immersion speed was 20 millimeters per second and the immersion depth was 5 millimeters. Immersion time was 5 seconds.

Ten trials were run for each flux. The specific gravity and temperature of the flux was recorded each time. The coupon was grasped with forceps and dipped into a beaker of flux. It was slowly withdrawn from the flux and then touched to filter paper for 2 seconds to drain excess flux. The coupon was then placed in the sample clip and mounted on the wetting balance jib. The test was not begun until the sample clip was no longer moving on the jib. The sample was preheated and then the solder bath raised until the coupon was immersed to the proper depth in the solder for 5 seconds. The solder bath then lowered and the test was complete.

Individual force readings at 0.1 second intervals were printed as well as a force-time curve. A correlation factor was also recorded. A correlation factor is an interpretation of the similarity of the force-time curve and the theoretical curve. A value of 1.00 indicates that the actual force readings lie exactly on the theoretical curve. When a correlation factor of less than 0.750 was obtained, the force readings for that test were not used.

Tests have shown that optimum wetting takes place at 2 seconds of soldering time.* It is for this reason that force readings at 1 and 2 seconds are recorded and listed in Figure II-8. These values are the mean of 10 samples; standard deviations are also given.

An examination of force at both 1 second and 2 seconds was completed in order to rate the fluxes for solderability. It was believed that a high force reading at 2 seconds is an indication of good wetting. The force reading at 1 second should be close to the 2-second force reading because it indicates a constant force over a 2-second time rather than an increasing force over the same time period. When the force reading at 1 second was significantly lower than the force reading at 2 seconds, the flux was rated lower. It is important to note that this method of rating the fluxes is an arbitrary method.

Generally, the non-rosin fluxes gave the best solderability results. The RMA flux that rated highest was Alpha 620F. This flux had the most ionic contamination of all the RMA fluxes tested. Alpha 611F and Kester 197 were the next best rosin fluxes for solderability. The RA fluxes, which rated in the lower third of the solderability results, left a residue on the sample clip that could not be removed with solvent cleaning. These residues required mechanical removal before another test could be begun.

---

*Becker, Gert, "European Solderability Control," Sixth Annual Soldering Technology Seminar, 17-18 February 1982.

FLUX	TEMP°F	MEASURED	RECOMMENDED*
ALPHA 611F	74.0	0.910	0.918
GARDINER 1235	76.8	0.875	0.880
KESTER 197	76.2	0.900	0.896
AMCO NO. 8	76.6	0.820	...
LONCO MIL-A-35-DA	77.0	0.870	0.870
COBAR 210-35	82.0	0.910	0.892
KENCO 365	74.5	0.910	...
ALPHA 620F	73.7	0.905	0.907
LONCO 106-A-35-X-MIL	82.5	0.885	0.887
KESTER 1585-MIL	75.7	0.895	0.890
ALPHA 711	76.8	0.935	0.936
KENCO 465-MIL	78.0	0.890	0.892
FRY R-8-20	78.0	0.835	0.825
KENCO 413	81.6	0.865	0.869
GARDINER 2625	80.5	0.855	0.858
KESTER 1585	73.3	0.890	0.890
FRY 600	79.0	0.815	0.820
KESTER 2300	71.0	1.049	1.050
KESTER 2154	75.3	0.935	0.940
KESTER 2330	74.1	0.945	0.950
KENCO 183	74.1	0.865	0.852
LONCO 3355-11	73.5	0.945	0.955
LONCO 35-WS	75.7	0.860	0.865
ALPHA 709	73.6	0.875	0.873
ALPHA 850-33	70.9	0.900	0.909
COBAR 353	75.7	0.835	0.840
GARDINER 5425	71.0	0.900	0.895
GARDINER 5830	76.7	0.935	0.920
KESTER 2331	71.6	0.900	...
KENCO 192	74.4	0.935	0.945
AMCO 220-35	77.2	0.865	0.893
SUPERIOR NO. 30	66.5	1.038	...
SUPERIOR NO. 45	73.7	0.875	...
XERSIN 2015	73.6	0.835	...
ESF 30	72.7	1.031	...
ESS 33	77.8	1.036	...

*Recommended by manufacturer.

FIGURE II-1. Specific Gravity.

FLUX	pH
ALPHA 611F	6.31
GARDINER 1235	6.03
KESTER 197	4.26
AMCO NO. 8	3.40
LONCO MIL-A-35-DA	5.30
COBAR 210-35	4.04
KENCO 265	3.73
ALPHA 620F	6.43
LONCO 106-A-35X-MIL	5.16
KESTER 1585-MIL	3.18
ALPHA 711	3.76
KENCO 465-MIL	3.39
FRY R-8-20	3.22
KENCO 413	4.40
GARDINER 2625	3.95
KESTER 1585	3.42
FRY 600	2.96
KESTER 2300	1.29
KESTER 2154	2.46
KESTER 2330	1.59
KENCO 183	3.85
LONCO 3355-11	1.48
LONCO 35-WS	6.22
ALPHA 709	0.90
ALPHA 850-33	2.16
COBAR 353	8.51
GARDINER 5425	6.20
GARDINER 5830	2.25
KESTER 2331	7.00
KENCO 192	0.37
AMCO 220-35	1.99
SUPERIOR NO. 30	1.44
SUPERIOR NO. 45	0.66
XERSIN 2015	3.02
ESF 30	8.50
ESS 33	8.38

FIGURE II-2. pH.

FLUX	% SOLIDS
ALPHA 611F	34.0
GARDINER 1235	31.0
KESTER 197	33.0
AMCO NO. 8	16.8
LONCO MIL-A-35DA	39.6
COBAR 210-35	35.0
KENCO 365	43.0
ALPHA 620F	36.0
LONCO 106-A-35X-MIL	36.0
KESTER 1585-MIL	35.2
ALPHA 711	57.0
KENCO 465-MIL	35.0
FRY R-8-20	24.0
KENCO 413	33.0
GARDINER 2625	24.0
KESTER 1585	35.0
FRY 600	12.9
KESTER 2300	31.2
KESTER 2154	16.2
KESTER 2330	12.3
KENCO 183	12.1
LONCO 3355-11	16.8
LONCO 35-WS	27.0
ALPHA 709	11.0
ALPHA 850-33	32.0
COBAR 353	32.0
GARDINER 5425	33.7
GARDINER 5830	35.8
KESTER 2331	17.6
KENCO 192	35.0
AMCO 220-35	32.0
SUPERIOR NO. 30	12.8
SUPERIOR NO. 45	18.0
XERSIN 2015	16.3
ESF 30	13.2
ESS 33	19.5

FIGURE II-3. Percent Solids.

FLUX	COLOR
ALPHA 611F	VERY PALE GREEN
GARDINER 1235	DARK GREEN
KESTER 197	NO GREEN; YELLOW
AMCO NO. 8	PALE GREEN
LONCO MIL-A-35-DA	VERY PALE GREEN
COBAR 210-35	GREEN
KENCO 365	DARK GREEN
ALPHA 620F	DARK GREEN
LONCO 106-A-35X-MIL	PALE GREEN
KESTER 1585-MIL	PALE GREEN
ALPHA 711	DARK GREEN
KENCO 465-MIL	DARK GREEN
FRY R-8-20	PALE GREEN
KENCO 413	DARK GREEN
GARDINER 2625	DARK GREEN
KESTER 1585	DARK GREEN
FRY 600	GREEN
KESTER 2300	DARK GREEN
KESTER 2154	NO GREEN
KESTER 2330	DARK GREEN
KENCO 183	NO GREEN
LONCO 3355-11	DARK GREEN
LONCO 35-WS	PALE GREEN
ALPHA 709	GREEN
ALPHA 850-33	DARK GREEN
COBAR 353	GREEN
GARDINER 5425	GREEN
GARDINER 5830	NO GREEN
KESTER 2331	GREEN
KENCO 192	DARK GREEN
AMCO 220-35	NO TEST
SUPERIOR NO. 30	BRIGHT GREEN
SUPERIOR NO. 45	BRIGHT GREEN
XERSIN 2015	BRIGHT GREEN
ESF 30	SLIGHTLY GREEN
ESS 33	BRIGHT GREEN

FIGURE II-4. Beilstein Test.

FLUX	COLOR
ALPHA 611F	NO VISIBLE RESIDUE
GARDINER 1235	SLIGHT GREY
KESTER 197	VERY SLIGHT GREY
AMCO NO. 8	NO COLOR CHANGE
LONCO MIL-A-35-DA	NO COLOR CHANGE
COBAR 210-35	NO COLOR CHANGE
KENCO 365	NO COLOR CHANGE
ALPHA 620F	SLIGHT GREY CIRCLE
LONCO 106-A-35X-MIL	VERY SLIGHT GREY CIRCLE
KESTER 1585-MIL	GREY CIRCLE
ALPHA 711	VERY GREY CIRCLE
KENCO 465-MIL	GREY CIRCLE
FRY R-8-20	GREY CIRLCE
KENCO 413	GREY CIRCLE
GARDINER 2625	GREY CIRCLE
KESTER 1585	GREY CIRLCE
FRY 600	GREY/WHITE CIRCLE
KESTER 2300	WHITE CIRCLE
KESTER 2154	NO COLOR CHANGE
KESTER 2330	WHITE CIRCLE WITH YELLOW PERIMETER
KENCO 183	NO COLOR CHANGE
LONCO 3355-11	WHITE CIRCLE WITH YELLOW PERIMETER
LONCO 35-WS	SLIGHT GREY CIRCLE
ALPHA 709	WHITE CIRCLE WITH GREY PERIMETER
ALPHA 850-33	WHITE CIRCLE
COBAR 353	GREY CIRCLE
GARDINER 5425	SLIGHT GREY CIRCLE
GARDINER 5830	NO COLOR CHANGE
KESTER 2331	WHITE CIRCLE WITH YELLOW GREY PERIMETER
KENCO 192	WHITE CIRLCE
AMCO 220-35	GREY CIRCLE WITH YELLOW WHITE PERIMETER
SUPERIOR NO. 30	WHITE CIRLCE
SUPERIOR NO. 45	WHITE CIRLCE
XERSIN 2015	NO COLOR CHANGE
ESF 30	VERY SLIGHT GREY CIRCLE
ESS 33	VERY SLIGHT GREY CIRCLE

FIGURE II-5. Silver Chromate Paper Test.

FLUX	% Cl^-
ALPHA 611F	0.00282
GARDINER 1235	0.0149
KESTER 197	0.00499
AMCO NO. 8	0.0380
LONCO MIL-A-35-DA	0.00691
COBAR 210-35	NONE DETECTED
KENCO 365	0.419
ALPHA 620F	NONE DETECTED
LONCO 106-A-35X-MIL	0.0307
KESTER 1585-MIL	0.182
ALPHA 711	0.450
KENCO 465-MIL	0.282
FRY R-8-20	0.137
KENCO 413	0.325
GARDINER 2625	0.263
KESTER 1585	0.246
FRY 600	0.493
KESTER 2300	0.706
KESTER 2154	0.0159
KESTER 2330	3.014
KENCO 183	0.0159
LONCO 3355-11	2.63
LONCO 35-WS	0.0134
ALPHA 709	2.25
ALPHA 850-33	1.058
COBAR 353	0.0203
GARDINER 5425	0.232
GARDINER 5830	0.00048
KESTER 2331	1.824
KENCO 192	2.47
AMCO 220-35	3.35
SUPERIOR NO. 30	2.18
SUPERIOR NO. 45	3.20
XERSIN 2015*	0.977
ESF 30*	0.031
ESS 33*	0.061

*Endpoint reaction difficult to distinguish.

FIGURE II-6. Silver Nitrate Titration.

FLUX	CARRIER
ALPHA 611F	ISOBUTANOL + ISOPROPANOL
GARDINER 1235	ISOPROPANOL
KESTER 197	ISOPROPANOL
AMCO NO. 8	ISOPROPANOL
LONCO MIL-A-35-DA	ISOBUTANOL
COBAR 210-35	ISOPROPANOL
KENCO 365	ISOBUTANOL + ISOPROPANOL
ALPHA 620F	ISOPROPANOL
LONCO 106-A-35X-MIL	ISOPROPANOL + ISOBUTANOL + n-PROPANOL
KESTER 1585-MIL	n-PROPANOL + ISOBUTANOL
ALPHA 711	n-PROPANOL + ISOBUTANOL
KENCO 465-MIL	n-PROPANOL
FRY R-8-20	ISOPROPANOL
KENCO 413	ISOPROPANOL
GARDINER 2625	n-PROPANOL + ISOBUTANOL
KESTER 1585	n-PROPANOL + ISOBUTANOL
FRY 600	ISOPROPANOL
KESTER 2300	POSSIBLE n-BUTANOL
KESTER 2154	ISOPROPANOL
KESTER 2330	ISOPROPANOL + METHANOL
KENCO 183	ISOPROPANOL
LONCO 3355-11	ISPROPANOL + POSSIBLE METHANOL
LONCO 35-WS	ISOPROPANOL
ALPHA 709	METHANOL
ALPHA 850-33	ISOPROPANOL + METHANOL
COBAR 353	ISOPROPANOL
GARDINER 5425	METHANOL + H_2O
GARDINER 5830	ISOPROPONAL + METHANOL
KESTER 2331	ISOPROPANOL
KENCO 192	ETHANOL
AMCO 220-35	NO TEST
SUPERIOR NO. 30	NO TEST
SUPERIOR NO. 45	NO TEST
XERSIN 2015	NO TEST
ESF 30	NO TEST
ESS 33	NO TEST

FIGURE II-7. Flux Carriers.

FLUX	MEAN FORCE AT T = 1 SEC	MEAN FORCE AT T = 2 SEC	STANDARD DEVIATION AT T = 1 SEC	STANDARD DEVIATION AT T = 2 SEC	FLUX TYPE
KENCO 183	8.55	8.88	0.489	0.475	NR
KESTER 2300	8.32	8.34	1.01	0.798	NR
GARDINER 5425	7.67	8.02	0.590	0.505	NR
KESTER 2331	7.30	7.97	0.934	0.792	NR
ALPHA 850-33	7.86	7.92	0.476	0.479	NR
LONCO 3355-11	7.10	7.82	0.742	0.505	NR
AMCO 220-35	7.05	7.55	0.579	0.387	NR
ALPHA 709	6.73	7.54	2.60	0.627	NR
SUPERIOR NO. 45	7.37	7.52	0.614	0.628	NR
KESTER 2330	7.37	7.48	0.588	0.550	NR
FRY 600	7.37	7.44	0.437	0.456	NR
ALPHA 620F	7.22	7.33	0.543	0.531	RMA
KENCO 192	7.52	7.28	0.529	0.461	NR
SUPERIOR NO. 30	6.78	7.23	0.682	0.610	NR
GARDINER 5830	4.93	7.32	1.18	0.628	NR
ALPHA 611F	4.49	7.29	1.09	0.384	RMA
KESTER 197	6.69	7.22	1.15	0.809	RMA
COBAR 353	6.62	7.02	0.572	0.534	NR
FRY R-8-20	5.91	7.08	0.814	0.559	RA
GARDINER 1235	5.93	7.04	0.830	0.707	RMA
KESTER 1585	6.58	6.85	0.448	0.491	RA
KESTER 2154	6.34	6.71	0.688	0.647	NR
ALPHA 711	6.30	6.69	0.716	0.428	RA
GARDINER 2625	6.51	6.67	1.05	0.714	RA
KESTER 1585-MIL	6.31	6.66	0.623	0.568	RA
KENCO 413	6.28	6.51	0.791	0.686	RA
KENCO 465-MIL	6.51	6.37	0.807	0.609	RA
XERSIN 2015	5.04	6.97	1.04	0.680	NR
AMCO NO. 8	3.20	5.59	1.99	1.37	RMA
LONCO 35-WS	3.45	5.25	0.77	0.53	NR
LONCO 106-A-35X-MIL	2.60	5.24	2.21	1.15	RA
MULTICORE ESS 33	2.78	6.52	0.844	0.380	NR
MULTICORE ESF 30	1.73	6.51	1.25	0.577	NR
LONCO MIL-A-35-DA	0.72	5.45	1.96	1.06	RMA
COBAR 210-35	1.62	4.59	1.25	0.758	RMA
KENCO 365	-2.79	2.58	2.79	1.04	RMA

FIGURE II-8. Solderability Results in Descending Order.

III. PROCEDURE

The general procedure for testing was as depicted in Figure III-1. The process parameters for each step were carefully monitored and are described in detail below. Specific information on the equipment used in this study is located in Appendixes A, B, and C.

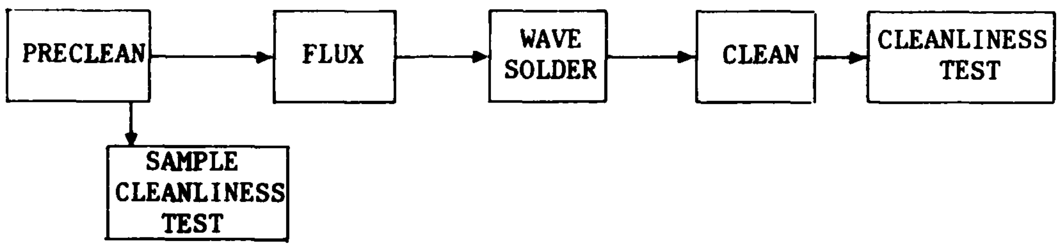

FIGURE III-1. General Process Procedure.

The test boards used in this study were fabricated at the in-house printed wiring board manufacturing facility. The test board is a modified IPC-B-25 pattern as shown in Figure III-2. It was plated using a semi-additive plating process with 60/40 tin/lead over 1 ounce copper on GF type epoxy laminate per MIL-P-13949. A hot wax reflow was used, therefore, no flux contacted the boards during the fabrication process. The line spacing of the comb patterns was 0.025 inch, 0.0125 inch, and 0.0065 inch. The test board had a surface area of 15 square inches.

The boards, once received from the printed wiring board shop, were inspected for electrical continuity of the fine (0.0065 inch) comb pattern. They were then numbered and placed in the vapor degreasing basket for pre-cleaning.

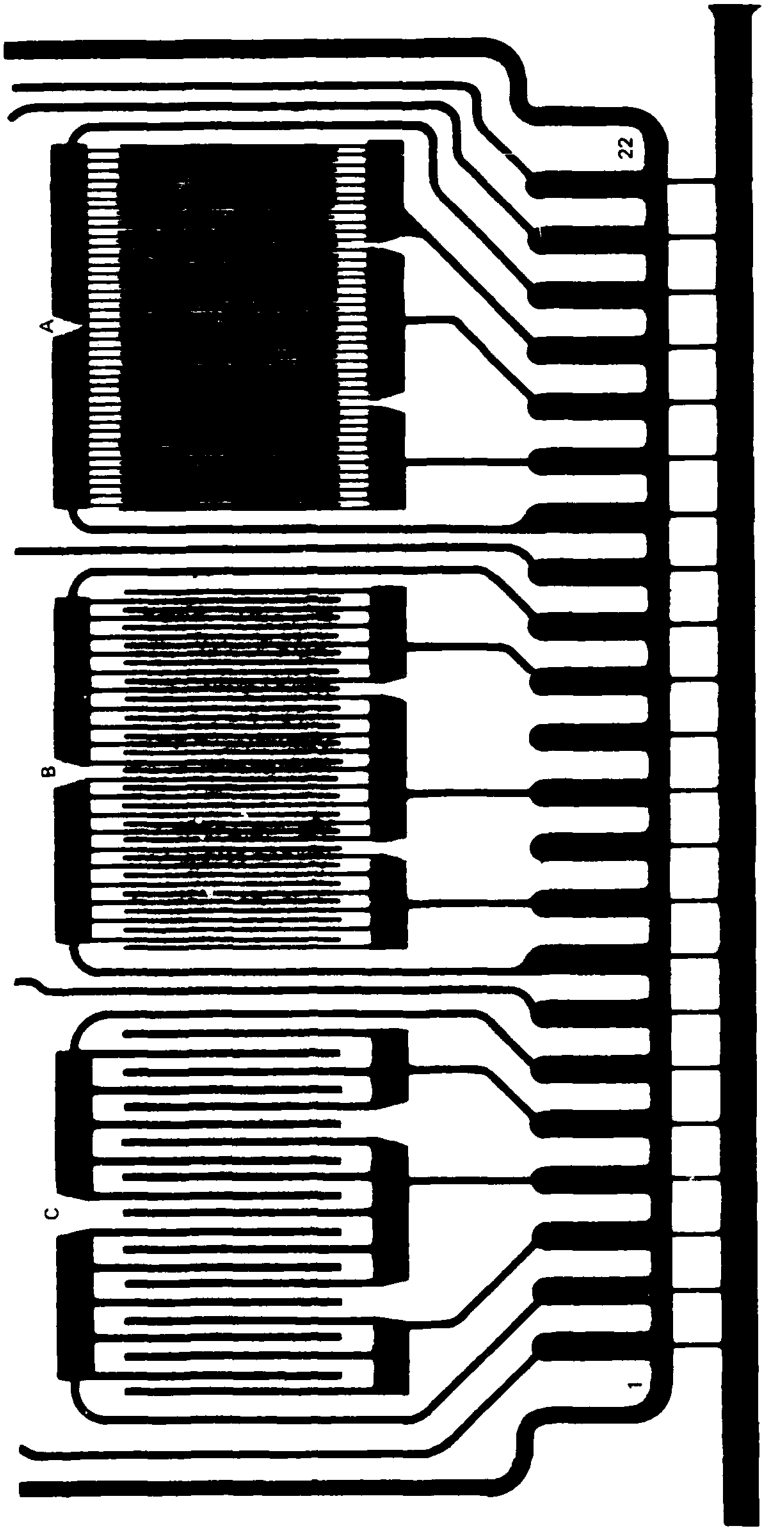

FIGURE III–2. SAMPLE PRINTED WIRING BOARD.

The precleaning of the boards was a two-step process. Both solvent and aqueous cleaning were used to remove all plating and handling residues in order to begin the testing with known clean samples. The boards were first cleaned in the vapor degreaser with Freon TE and a 2-1-1 cycle. A 2-1-1 cycle is 2 minutes submerged in the boiling solvent, 1 minute submerged in the warm solvent, and 1 minute suspended in the vapors. For more detail see Appendix A. Sample boards were then placed on the aqueous cleaning conveyor and cleaned with a deionized water rinse.

After a batch of boards had been cleaned, a sample board was cleanliness tested. This test was to assure the cleanliness of the batch of test boards. If the sample board had more than 0.25 micrograms of contamination per square inch, the batch of boards was recleaned and another sample board was cleanliness tested.

After the boards were cleaned, they were handled with cotton-gloved hands only.

Each test, except where noted, was conducted with a sample size of three. The three boards were placed in the wave solder conveyor rack and positioned in the flux application station. The flux was applied with a pump spray bottle so as to minimize the amount of flux wasted and to apply the same amount of flux each time (see Figure III-3). The specific gravity, temperature, and pH were recorded each time a flux was used. The boards were sprayed with one spray per comb pattern, three sprays per side. Excess flux was allowed to drain for 2 or 3 seconds and then the rack was placed on the wave solder conveyor.

A Hollis Engineering Model TDL wave solder machine was used for all the wave soldering. The topside preheat temperature was measured on a finger of the 0.0065 inch comb pattern each time a test was run. The wave temperature and board immersion were also recorded. Board

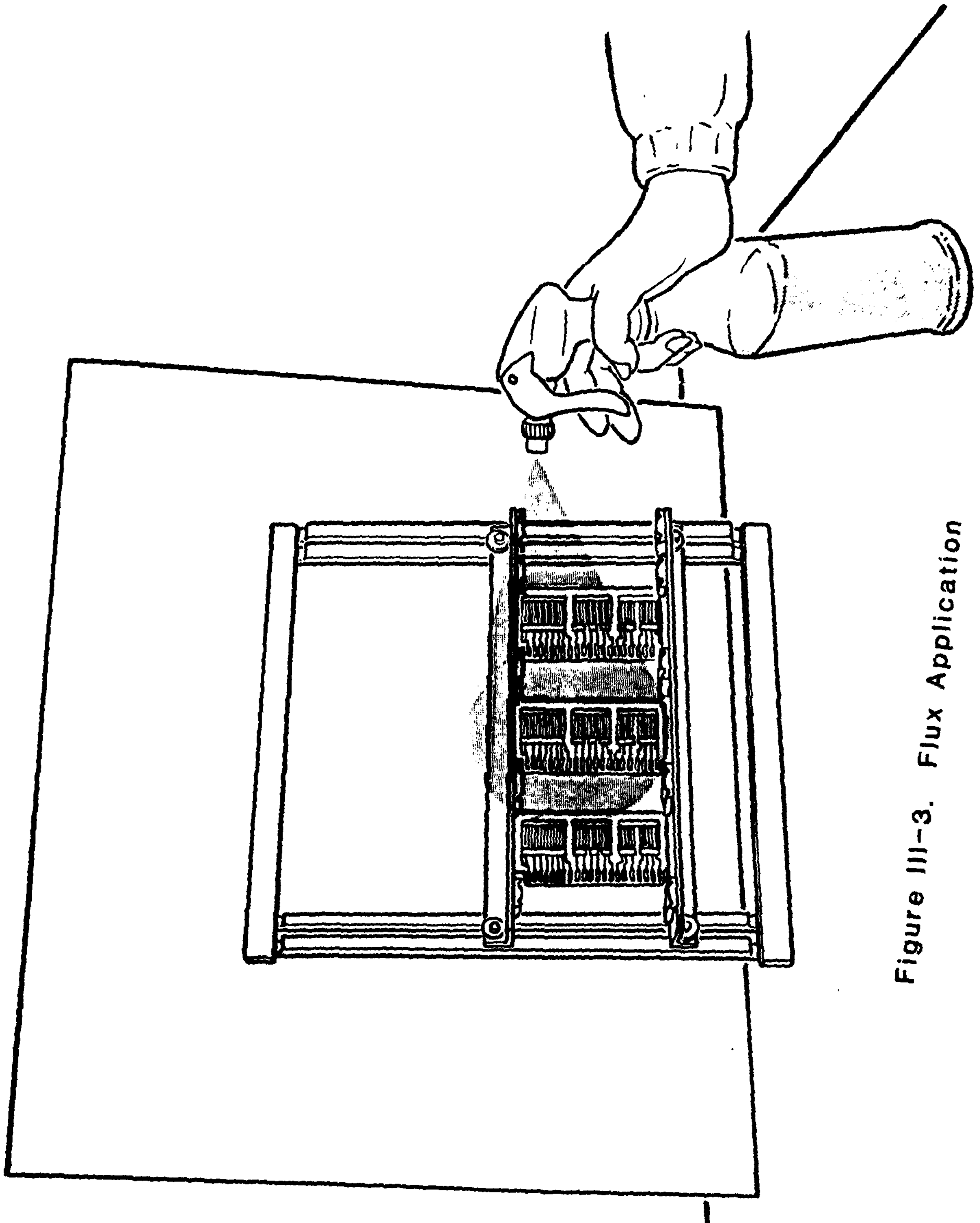

Figure III-3. Flux Application

immersion varied because of orientation on the conveyor rack. The conveyor speed was set at 2.75 feet per minute. This speed was selected to simulate the soldering speeds that are being used in industry today and gave an actual time in the wave of 1-1/2 to 2 seconds. The conveyor rack sat on the end of the wave solder machine for 1 minute to allow the boards to cool.

Cleaning of the boards was accomplished by one of three methods: solvent cleaning, aqueous cleaning, or a combination of both solvent and aqueous cleaning.

The solvent cleaning was performed in the vapor degreaser (for more details on the vapor degreaser see Appendix A.) Seven solvents were tested in the two different cycles (2-1-1 and 4-2-2). At the beginning of each test, specific gravity and temperature in each of the three tanks of the degreaser were recorded. These values were used to determine the alcohol percentages and when the solvent needed to be replaced. Only rosin-based fluxes were tested with this method.

The aqueous cleaning unit that was used in this study is a five-stage system. More details are given in Appendix B. The aqueous cleaning tests were conducted both with and without detergent. Varying concentrations of detergent, as well as varying purities of water were also tested. Parameters that were monitored for each test included conveyor speed, wash stage temperature, wash stage pH (if detergent was used), and final rinse conductivity. The resistivity of the final rinse was monitored at the point where the deionized water entered the system and was found to be 18 megohm-cm, but when the resistivity was measured at point of contact with the samples, it was considerably lower--2.5 megohm-cm. The 2.5 megohm-cm value is the resistivity value for deionized water used in the aqueous cleaner.

The combination cleaning tests required a sample size of four boards. After wave soldering, these four boards were cleaned using a vapor degreaser of Freon TE and 2-1-1 cycle. One of the four boards was then cleanliness tested to verify the level of cleanliness for solvent alone. The other three boards were further cleaned in the aqueous cleaning unit with deionized water only. These boards were then cleanliness tested and compared to the results for solvent cleaning.

Part of the test procedure was to quantify the amount of ionic contamination left on the test boards by the various fluxes and cleaning processes. This was accomplished with a modified Alpha Metals Ionograph. The modification used two Cole Parmer ion exchange columns to increase testing volume and to make maintenance of the Ionograph easier. A 75% isopropanol/25% deionized water solvent system was selected for testing. An explanation of this and other parameters is included in Appendix C.

The zero, or null point, that was selected for this testing was 0.02 micromhos per centimeter ($\mu\mho$/cm) or 50 megohm-cm. Calibration of the Ionograph was performed at the beginning of each test and every 4 hours using a known volume of standard sodium chloride (NaCl) solution. The results for the three test samples were converted into micrograms of contamination per square inches of board surface area ($\mu g/in^2$) and averaged. Except where noted, all of the values in the charts are mean values. The mean and standard deviation are listed in the tables following each chart.

The acceptance criteria that was used in this study was 10 micrograms per square inch. This value was adopted from the Naval Avionics Center Material Research Report 3-78, dated 29 August 1978 which specified 10 micrograms per square inch to be the equivalent of the 2 megohm-cm resistivity value that is outlined in MIL-P-28809.

There was some concern over the time between cleaning and cleanliness testing. It was thought that the residues might harden and become less soluble with time. This would result in test results with decreasing amounts of contamination. Another possible problem could result from particulate contamination falling onto the test boards which would result in increasing amounts of contamination. After the cleaning procedure was completed, the boards sat in the vapor degreaser basket without handling until the Ionograph was available for the next sample. Only three boards were tested at one time, but because of the Ionograph's indefinite test length, some tests ran as long as 1 hour each (average time was 20 minutes). With this in mind, careful documentation of the time that the cleaning procedure finished and the time that the cleanliness test began was maintained. An examination of these times and the results of the tests did not give any conclusive information because there was not a general increasing or decreasing trend of ionic contamination detected with time. Therefore, there was no direct correlation made between time from cleaning to cleanliness testing and the cleanliness test result.

IV. SOLVENT CLEANING

Since rosin-based fluxes were originally formulated to be cleaned in solvents, seven different halogenated solvents were chosen to test the fluxes. Non-rosin fluxes were not evaluated in a solvent cleaning system.

Test boards were pre-cleaned and processed according to Figure IV-I. The 2-1-1 and the 4-2-2 cycles were used on each flux tested. The solvents tested were: DuPont Freon TE (Figures IV-2 and IV-3), Baron-Blakeslee TMS Plus (Figures IV-4 and IV-5), Allied Chemical Genesolv DMS (Figures IV-6 and IV-7), DuPont Freon TMS (Figures IV-8 and IV-9), Dow Chemical Chlorothene SM (Figures IV-10 and IV-11), Electronic Packaging Associates (EPA) S-235 (Figures IV-12 and IV-13), and Dow Chemical Prelete (Figures IV-14 and IV-15).

All the RMA and the RA fluxes were tested in Freon TE. The values obtained from this solvent were used as baseline values to which the other solvents were compared.

Five RMA and five RA fluxes were chosen from each category to be further tested in the remaining six solvents. The five fluxes chosen from each category were selected according to their ionic cleanliness in Freon TE. Those fluxes that cleaned exceptionally well and those that cleaned exceptionally poor were selected so that great differences in cleaning ability of the solvents would be distinguishable. All of the RMA and RA fluxes were not tested due to time constraints.

Of the four fluorinated solvents, Freon TMS (Figures IV-8 and IV-9) cleaned the best for the processing procedures that were used. Freon TMS contains a higher percentage of alcohol than does Freon TE (Figures IV-2 and IV-3) but a lower percentage than Baron Blakeslee TMS

Plus (Figures IV-4 and IV-5) and Genesolv DMS (Figures IV-6 and IV-7). Freon TMS contains methanol, a more polar alcohol than the ethanol in the other solvents. The more polar constituent, methanol, allows the removal of more ionic contamination than do the less polar, larger alcohols.

The three chlorinated solvents that were tested had markedly different cleaning abilities. Each of these three solvents cleaned the RMA fluxes well, but the Chlorothene SM (Figures IV-10 and IV-11) and the EPA S-235 (Figures IV-12 and IV-13) were unable to remove a sufficient level of ionic contamination from the RA fluxes. The Dow Prelete (Figures IV-14 and IV-15), however, containing 7% of mixed alcohols, removed ionic contamination as well as Freon TMS. Again, the alcohol content establishes the ionic cleaning ability of the solvent.

Selection of the appropriate solvent for the process employed is a critical factor in final cleanliness. The process used in this study demonstrated that the fluorinated solvents with methanol and the chlorinated solvent with a high percent of mixed alcohols removed the most ionic contamination for each of the 10 fluxes tested. The fluorinated solvents with a high percentage of other alcohols and the remaining two chlorinated solvents cleaned well for the RMA fluxes but did not remove ionic contamination to an acceptable level in the RA flux tests.

The 2-1-1 and the 4-2-2 cleaning cycles did not, consistently, show any trends in cleaning ability. It is only necessary for the printed wiring assembly to remain in contact with the solvent long enough for the contamination to be removed. Freon TE, the baseline solvent, cleaned the samples equally well in both the 2-1-1 and the 4-2-2 cycles, therefore, in the interest of saving time, a 2-1-1 cycle was chosen for all remaining testing. In most cases, the other six solvents showed similar results between the 2-1-1 and the 4-2-2 cycles.

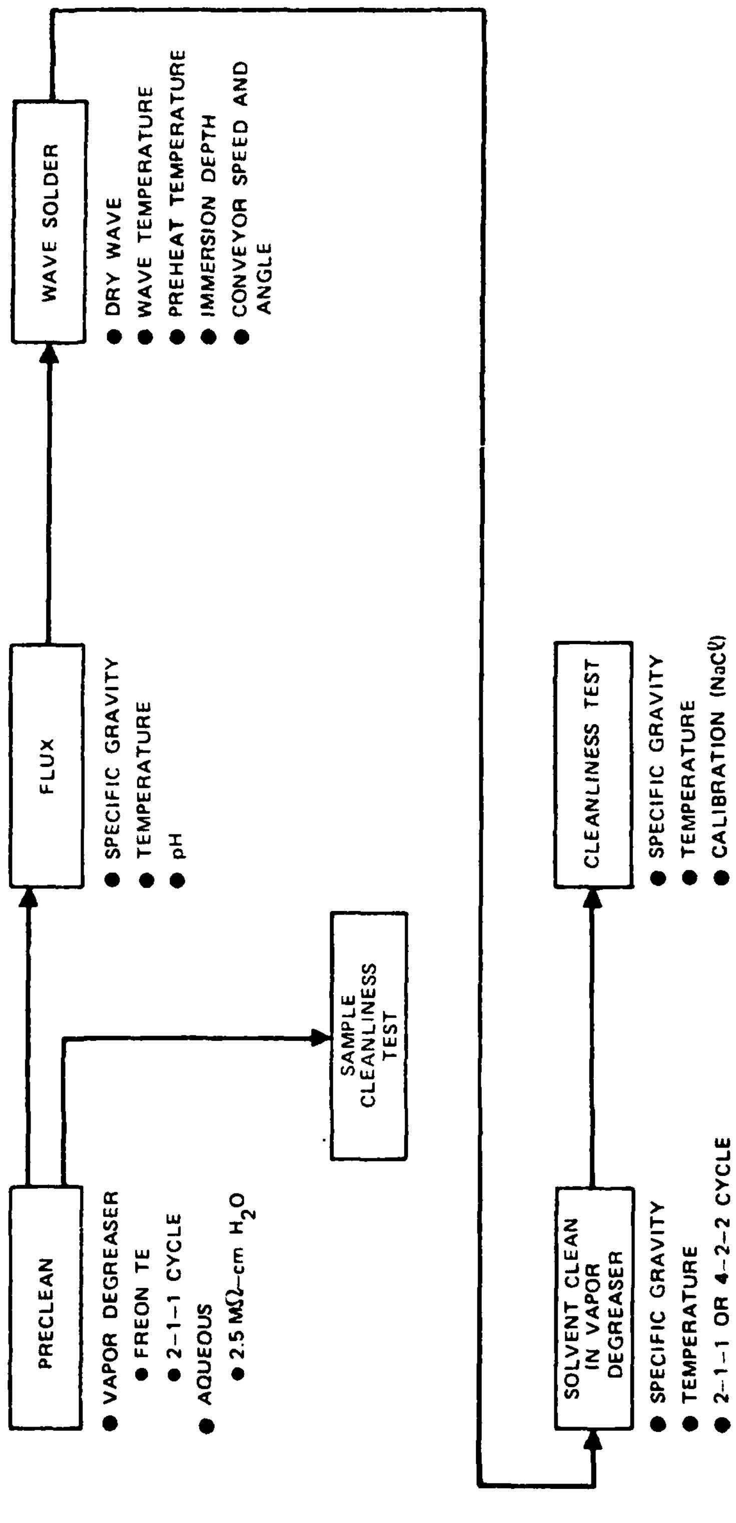

FIGURE IV–1. PROCESS PROCEDURE FOR SOLVENT TESTING.

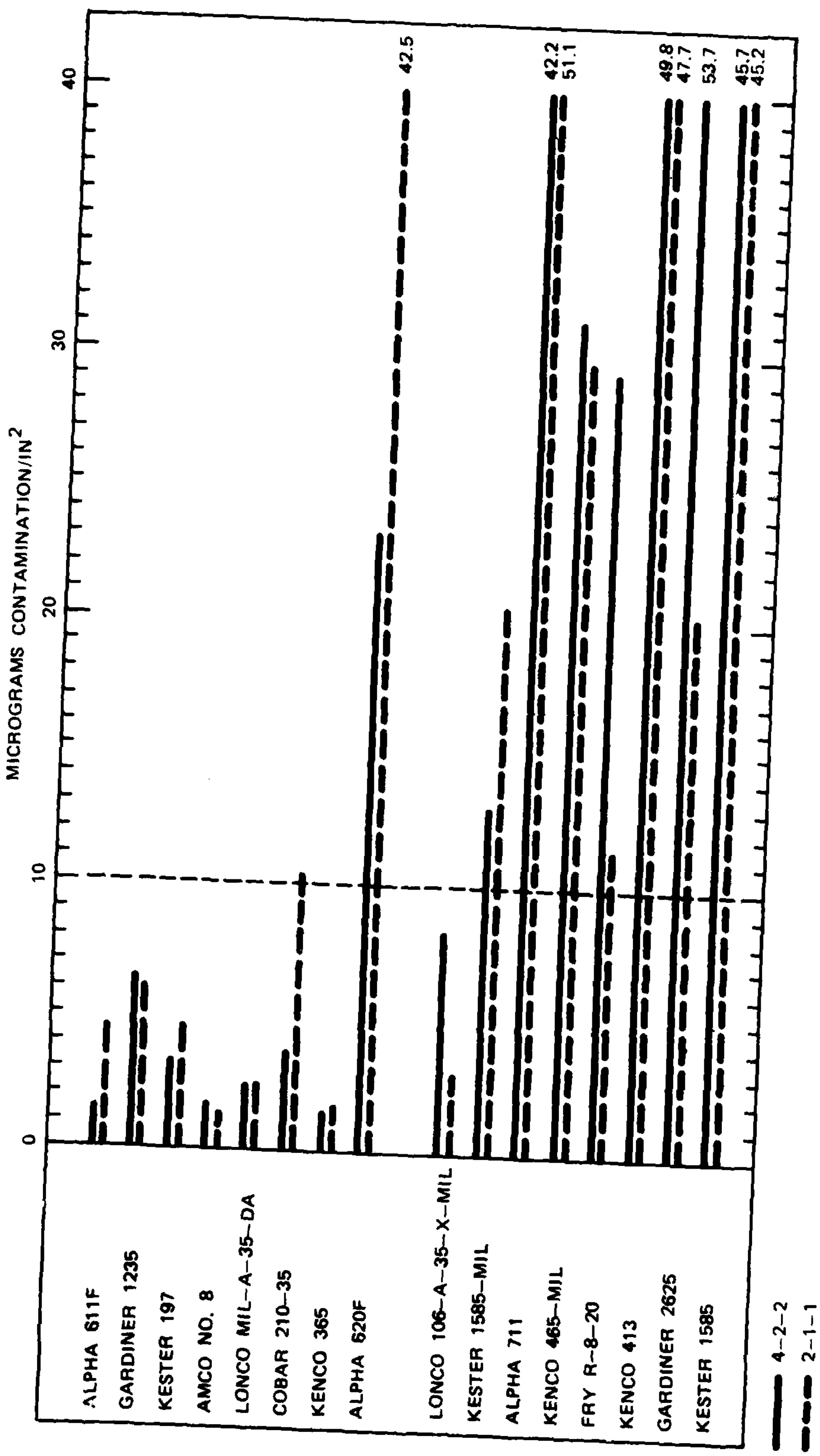

FIGURE IV-2. FREON TE, VARIOUS CLEANING TIMES.

FLUX	2-1-1 (µg/in^2)		4-2-2 (µg/in^2)	
	MEAN ($\bar{X}$)	STD DEV	MEAN ($\bar{X}$)	STD DEV
ALPHA 611F	5.51	0.732	1.56	0.439
KESTER 197	5.70	0.730	3.12	0.302
AMCO NO. 8	0.953	0.294	1.28	0.403
COBAR 210-35	11.0	3.58	3.91	1.09
ALPHA 620F	42.5	1.50	23.7	2.70
GARDINER 1235	7.01	2.25	7.29	0.706
LONCO MIL-A-35-DA	2.11	1.13	2.08	0.533
KENCO 365	1.77	0.213	1.29	0.327
LONCO 106-A-35X-MIL	2.99	0.139	8.33	0.753
KESTER 1585-MIL	21.2	2.15	13.7	1.49
KENCO 465-MIL	30.1	1.43	31.7	5.11
FRY R-8-20	12.7	4.38	29.0	5.67
GARDINER 2625	29.2	2.22	53.7	0.691
ALPHA 711	51.0	1.92	42.2	4.59
KENCO 413	47.7	3.46	49.8	1.26
KESTER 1585	45.2	1.88	45.8	11.2

FIGURE IV-3. Freon TE, Mean and Standard Deviation.

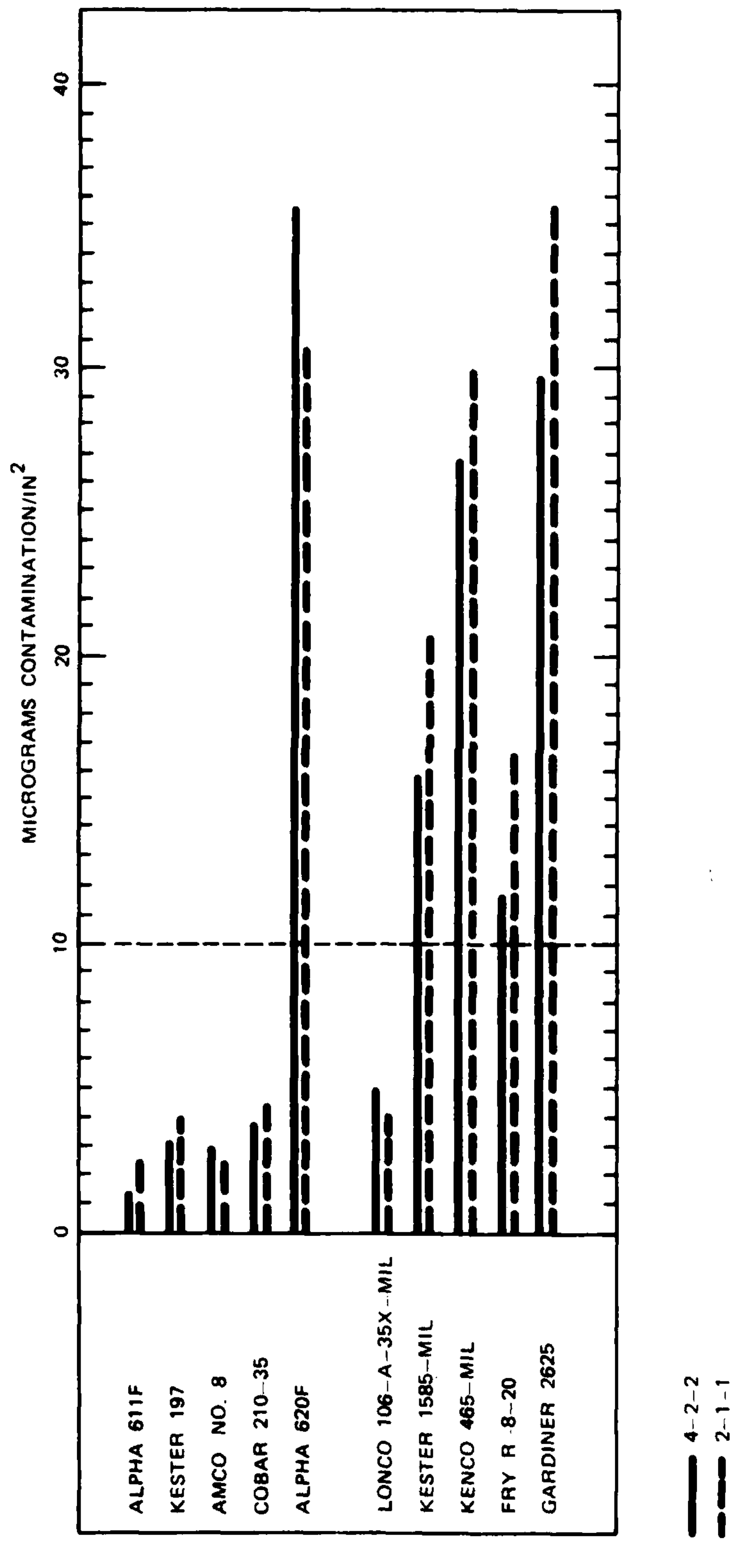

FIGURE IV–4. BARON–BLAKESLEE TMS PLUS, VARIOUS CLEANING TIMES.

FLUX	2-1-1 ($\mu g/in^2$)		4-2-2 ($\mu g/in^2$)	
	MEAN ($\bar{X}$)	STD DEV	MEAN ($\bar{X}$)	STD DEV
ALPHA 611F	2.50	0.144	1.70	0.137
KESTER 197	4.06	0.315	3.14	0.239
AMCO NO. 8	2.39	0.356	2.70	0.194
COBAR 210-35	4.83	0.339	4.40	0.481
ALPHA 620F	30.8	2.02	35.4	2.95
LONCO 106-A-35X-MIL	4.04	0.964	5.15	2.47
KESTER 1585-MIL	20.5	1.85	16.1	3.47
KENCO 465-MIL	29.3	3.18	27.0	2.72
FRY R-8-20	17.3	2.03	12.8	1.09
GARDINER 2625	35.8	0.899	29.6	0.942

FIGURE IV-5. Baron-Blakeslee TMS Plus, Mean and Standard Deviation.

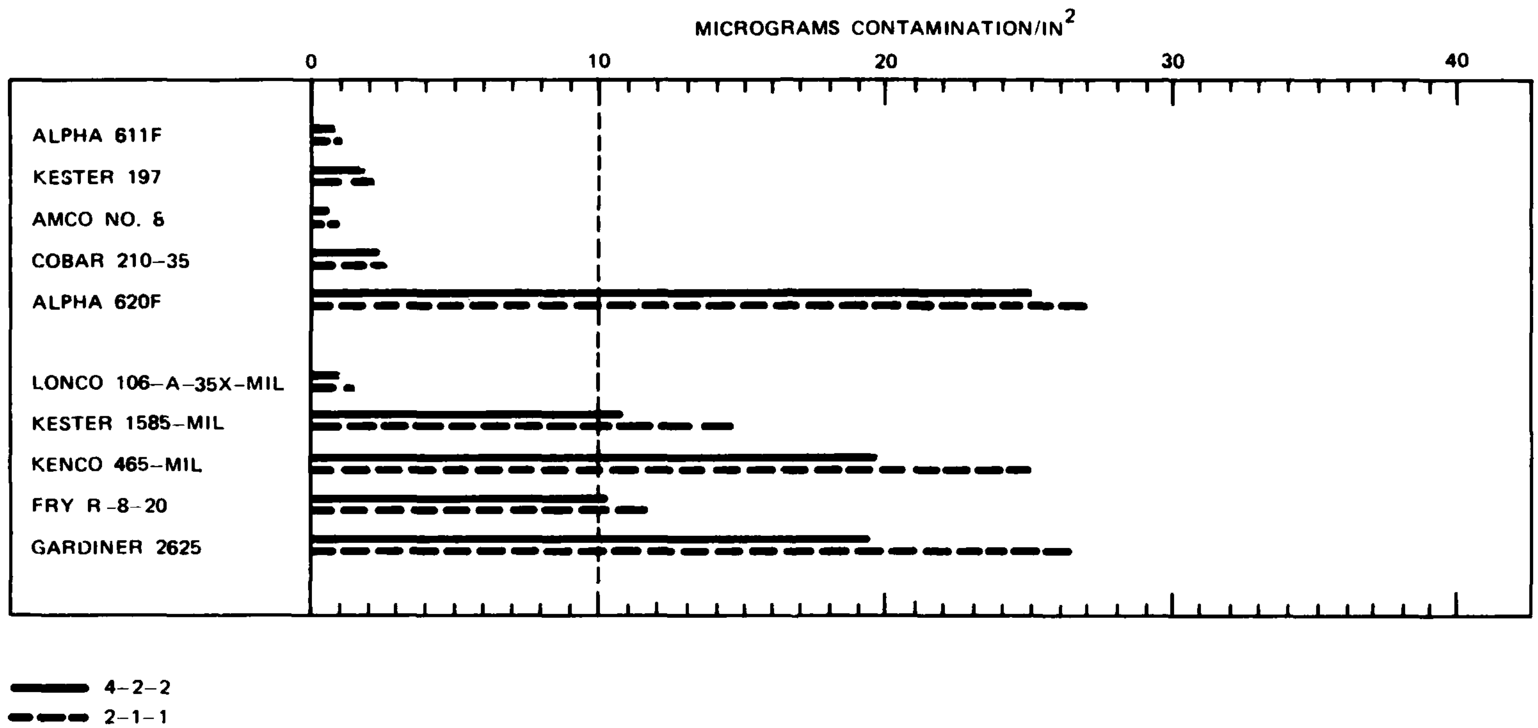

FIGURE IV-6. GENESOLV DMS, VARIOUS CLEANING TIMES.

FLUX	2-1-1 ($\mu g/in^2$)		4-2-2 ($\mu g/in^2$)	
	MEAN ($\bar{X}$)	STD DEV	MEAN ($\bar{X}$)	STD DEV
ALPHA 611F	0.775	0.348	0.761	0.0292
KESTER 197	1.85	0.298	1.59	0.163
AMCO NO. 8	0.552	0.262	0.349	0.0568
COBAR 210-35	2.17	0.147	2.22	0.187
ALPHA 620F	27.1	4.24	24.8	1.97
LONCO 106-A-35X-MIL	1.24	0.218	0.598	0.0568
KESTER 1585-MIL	14.1	1.22	11.1	1.21
KENCO 465-MIL	24.4	1.45	19.6	1.47
FRY R-8-20	12.0	1.22	10.3	3.75
GARDINER 2625	26.9	3.60	18.7	1.01

FIGURE IV-7. Genesolv DMS, Mean and Standard Deviation.

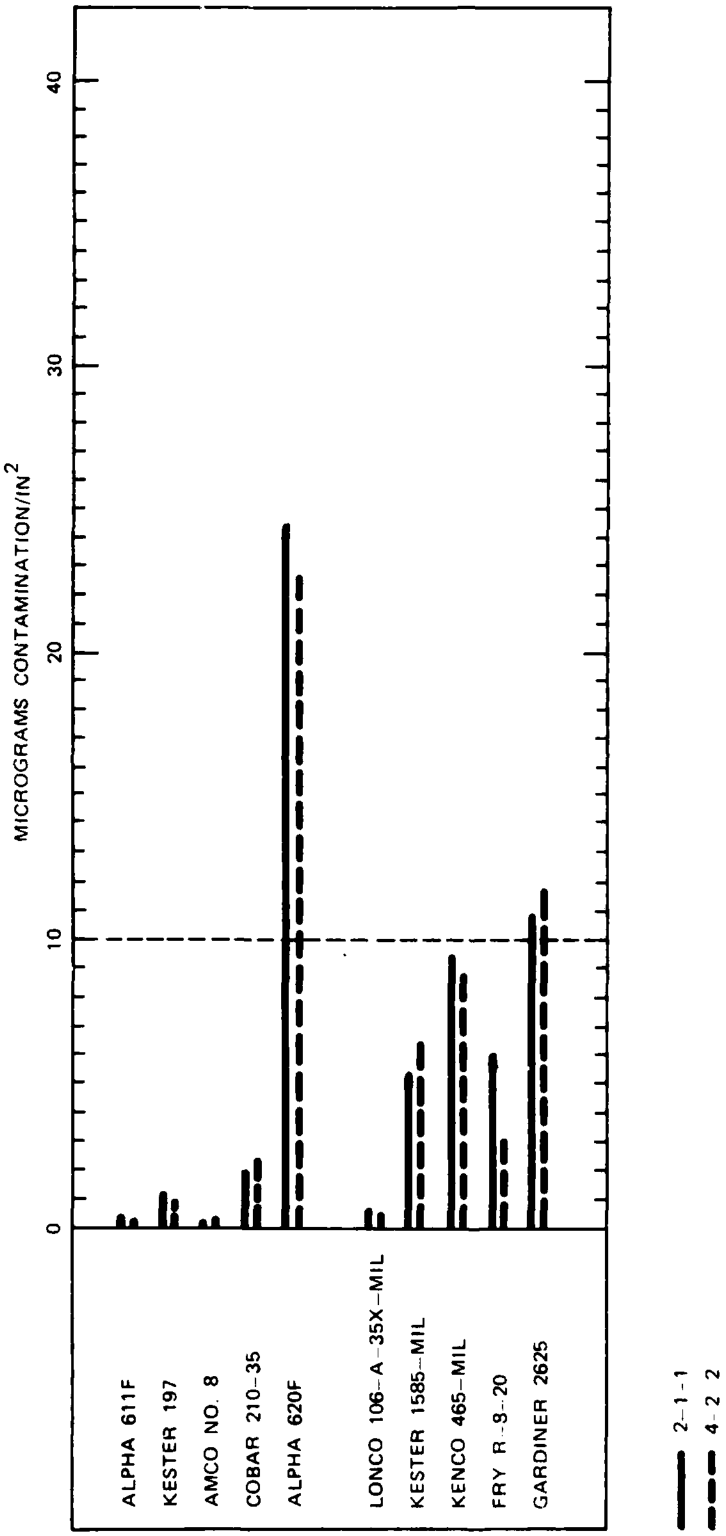

FIGURE IV-8. FREON TMS, VARIOUS CLEANING TIMES.

FLUX	2-1-1 (μg/in^2)		4-2-2 (μg/in^2)	
	MEAN ($\bar{X}$)	STD DEV	MEAN ($\bar{X}$)	STD DEV
ALPHA 611F	0.405	0.0602	0.395	0.0396
KESTER 197	1.00	0.201	0.928	0.164
AMCO NO. 8	0.220	0.0410	0.290	0.0844
COBAR 210-35	1.97	0.0613	2.11	0.149
ALPHA 620F	24.7	3.57	22.6	1.99
LONCO 106-A-35X-MIL	0.620	0.106	0.588	0.145
KESTER 1585-MIL	5.78	0.969	6.64	0.451
KENCO 465-MIL	9.79	0.916	8.62	0.745
FRY R-8-20	6.13	1.64	2.71	0.231
GARDINER 2625	11.0	3.60	11.9	0.535

FIGURE IV-9. Freon TMS, Mean and Standard Deviation.

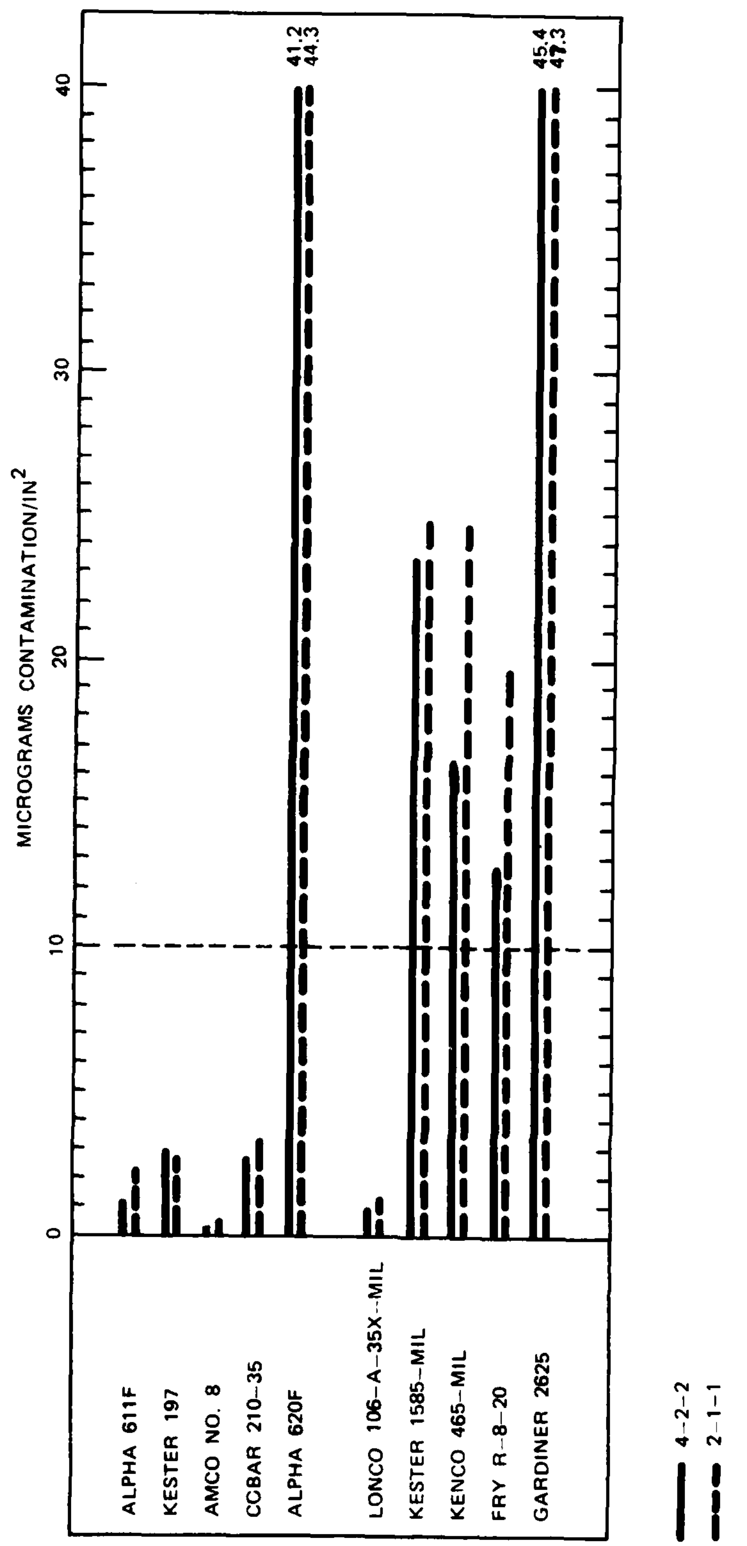

FIGURE IV–10. CHLOROTHENE SM, VARIOUS CLEANING TIMES.

FLUX	2-1-1 ($\mu g/in^2$)		4-2-2 ($\mu g/in^2$)	
	MEAN ($\bar{X}$)	STD DEV	MEAN ($\bar{X}$)	STD DEV
ALPHA 611F	2.24	0.179	1.72	0.211
KESTER 197	2.57	0.489	2.64	0.215
AMCO NO. 8	0.428	0.199	0.245	0.0518
COBAR 210-35	3.17	0.0754	2.57	0.243
ALPHA 620F	44.3	0.579	41.2	0.685
LONCO 106-A-35X-MIL	1.28	0.364	0.832	0.177
KESTER 1585-MIL	24.7	0.535	23.6	1.80
KENCO 465-MIL	24.7	3.99	16.6	1.59
FRY R-8-20	19.7	0.340	12.9	1.19
GARDINER 2625	47.3	0.860	45.4	2.61

FIGURE IV-11. Chlorothene SM, Mean and Standard Deviations.

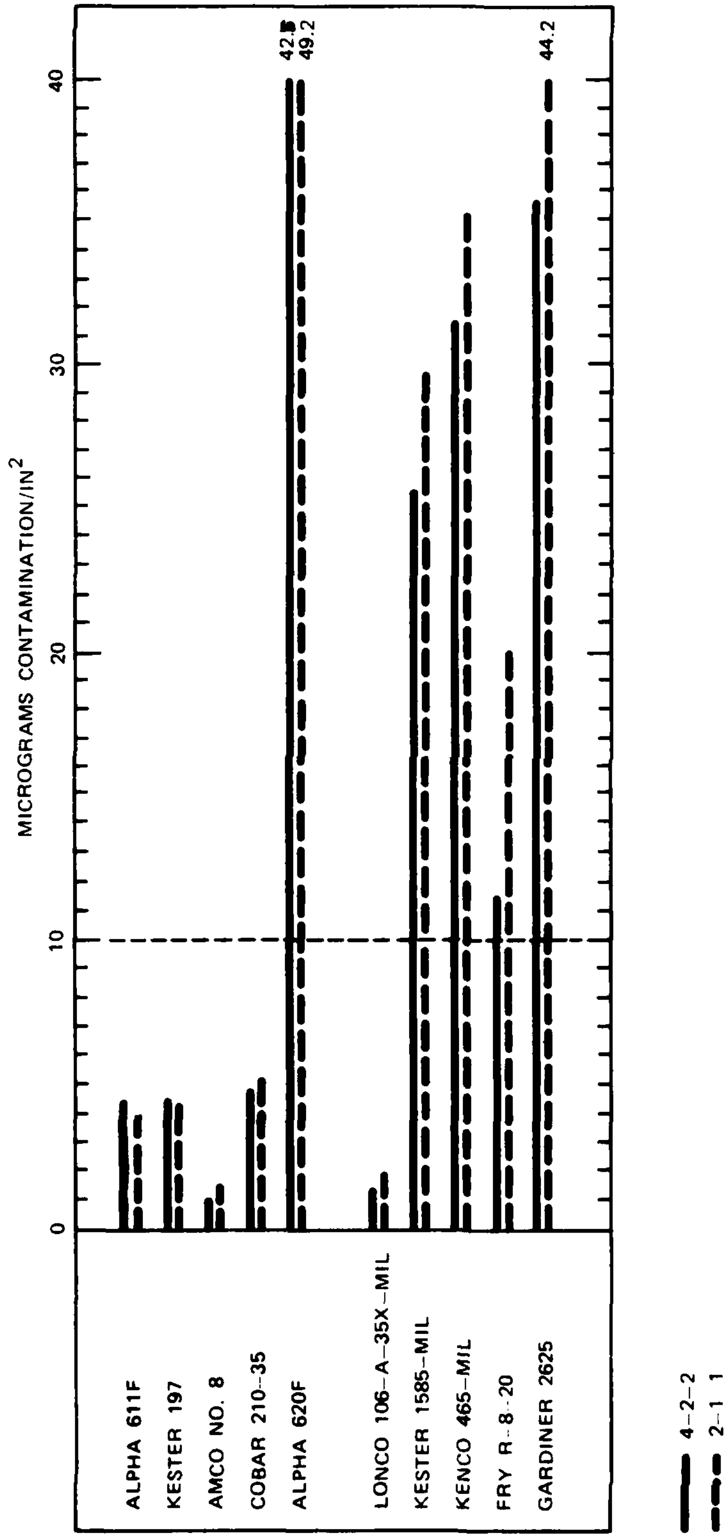

FIGURE IV-12. E.P.A. S-235, VARIOUS CLEANING TIMES.

FLUX	2-1-1 ($\mu g/in^2$)		4-2-2 ($\mu g/in^2$)	
	MEAN ($\bar{X}$)	STD DEV	MEAN ($\bar{X}$)	STD DEV
ALPHA 611F	3.83	0.236	4.43	0.199
KESTER 197	4.42	0.429	4.68	0.274
AMCO NO. 8	1.27	0.0829	1.07	0.0843
COBAR 210-35	5.41	0.442	5.18	0.597
ALPHA 620F	49.2	3.10	42.5	1.46
LONCO 106-A-35X-MIL	1.87	0.608	1.58	0.135
KESTER 1585-MIL	29.2	2.10	26.1	4.18
KENCO 465-MIL	35.2	1.24	31.9	4.76
FRY R-8-20	20.4	0.613	12.8	1.64
GARDINER 2625	44.2	2.56	36.3	1.74

FIGURE IV-13. EPA S-235, Mean and Standard Deviation.

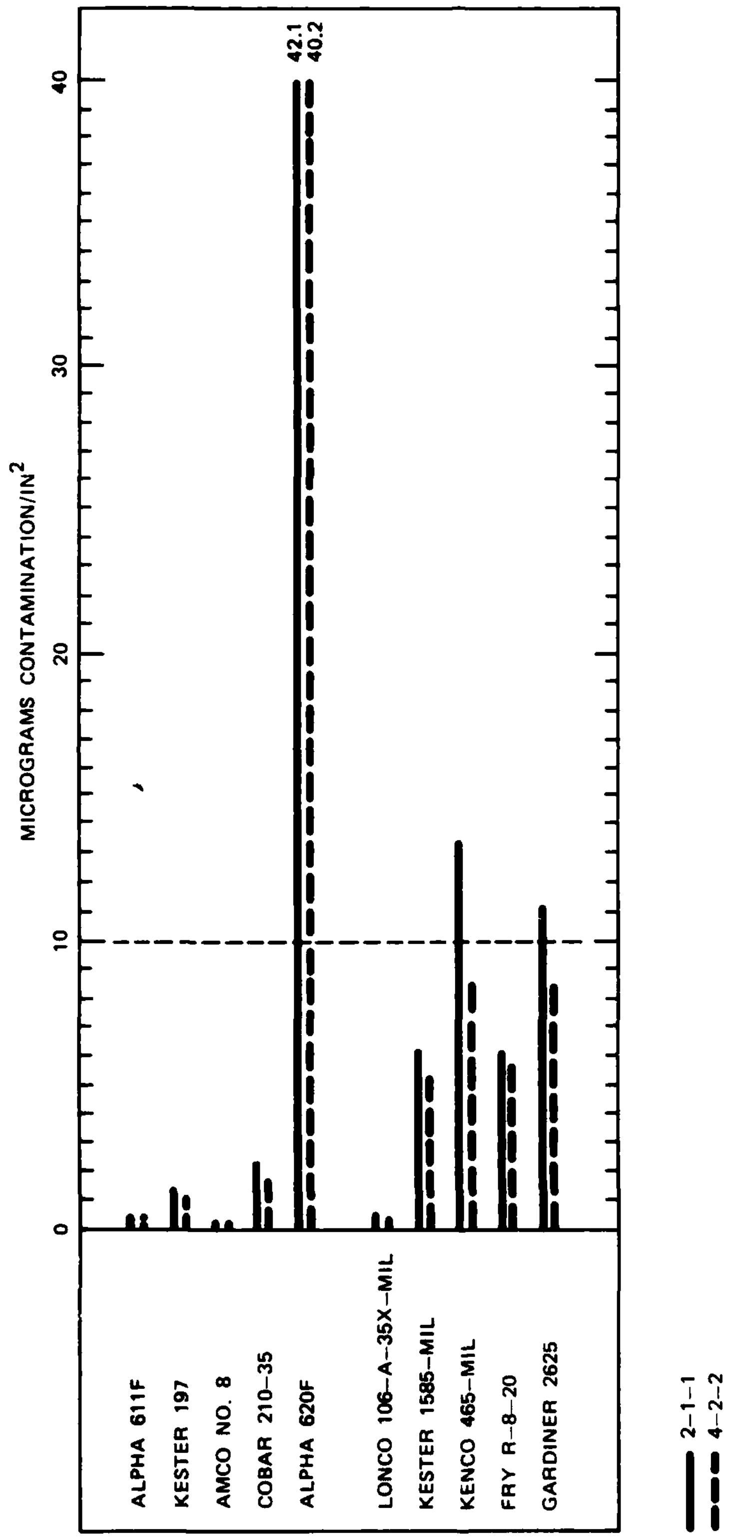

FIGURE IV–14. DOW PRELETE, VARIOUS CLEANING TIMES.

FLUX	2-1-1 ($\mu g/in^2$)		4-2-2 ($\mu g/in^2$)	
	MEAN ($\bar{X}$)	STD DEV	MEAN ($\bar{X}$)	STD DEV
ALPHA 611F	0.349	0.0330	0.329	0.109
KESTER 197	1.66	0.491	0.934	0.204
AMCO NO. 8	0.240	0.0917	0.235	0.113
COBAR 210-35	2.36	0.221	2.09	0.199
ALPHA 620F	42.1	3.73	40.2	1.88
LONCO 106-A-35X-MIL	0.354	0.113	0.240	0.973
KESTER 1585-MIL	6.55	1.01	5.58	1.37
KENCO 465-MIL	13.7	3.56	9.05	0.849
FRY R-8-20	6.94	1.90	6.50	0.440
GARDINER 2625	11.7	0.655	8.43	1.12

FIGURE IV-15. Dow Prelete, Mean and Standard Deviation.

V. AQUEOUS CLEANING

The next step was to investigate the effectiveness of aqueous cleaning of both non-rosin and rosin-based fluxes. The test boards were processed according to the flowchart outlined in Figure V-1.

The first set of tests were conducted to determine how well various purities of water cleaned non-rosin fluxes. The three different water purities tested were tap water, 2.5×10^5 ohm-cm deionized water, and 2.5×10^6 ohm-cm deionized water. Results of the analysis of the tap water used in testing are located in Appendix B. Figures V-2 through V-7 show the values obtained for the different water purities. Testing of Superior No. 30, Superior No. 45, Xersin 2015, Multicore ESF 30, and Multicore ESS 33 with tap water and 2.5×10^5 ohm-cm deionized water was not attempted. The results show that the 2.5×10^5 ohm-cm deionized water removed more ionic contamination than the other water purities. These results are unexplained. An important note is that very few fluxes passed ionic cleanliness testing with aqueous cleaning alone.

Additional testing with detergent cleaning of all flux types was performed. The detergents that were tested are Alpha 2100, Gardiner 4800, Kester 5776, and Lonco 520. The RMA and RA fluxes were cleaned in 5% Kester 5776, 5% Alpha 2100, and 5% Lonco 520 (see Figures V-8 through V-13). No detergent was able to clean any of the RA fluxes to an acceptable ionic level. Kester 5776 was the best detergent for RMA fluxes, since six of the eight fluxes that were tested passed the ionic cleanliness test.

Non-rosin fluxes were also tested in a 5% Kester 5776 detergent solution (see Figures V-14 and V-15). Ten fluxes passed ionic cleanliness testing. Kester 5776 was selected for wide scale testing because it cleaned both the rosin and non-rosin fluxes better than the other detergents that were tested.

Next, the concentration of detergent was varied for cleaning of non-rosin fluxes. Figures V-15 through V-20 show the test results for 5% and 1% Kester 5776 and 5% and 1% Alpha 2100. The 5% Kester 5776 was the best concentration of detergent for removing ionic contamination. A comparison of all detergents at 1% was then made (see Figures V-17, V-19, V-21, V-22, V-23). Lonco 520 was the best detergent at the 1% concentration; four fluxes passed ionic cleanliness testing.

The working life of these alkaline detergents was monitored through pH measurements. If a buffer is added to the detergent, the pH value will be stabilized until the detergent needs to be changed. Detergents with buffers are easier to maintain. Tests were conducted on the detergents included in the study and it was found that all detergents had buffers.

The test results show that even very pure water will not remove non-rosin flux residues. Some detergent, or saponifier, must be used to achieve acceptable ionic cleanliness levels. Careful monitoring of the pH of the detergent is important to determine when the detergent is no longer useful. Aqueous cleaning of both RMA and non-rosin fluxes with adequate levels of detergent resulted in acceptable ionic cleanliness levels. RA fluxes did not pass ionic cleanliness testing for any detergent tested.

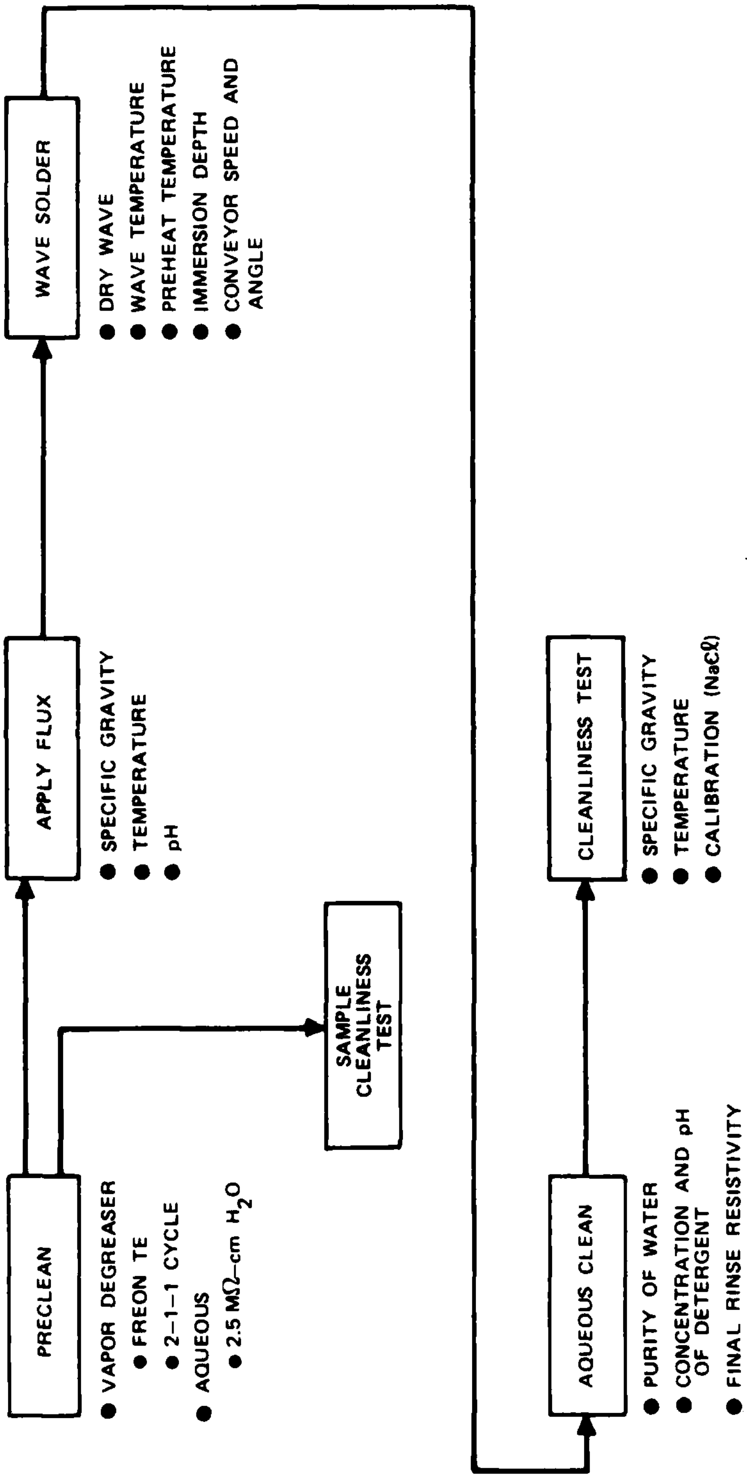

FIGURE V-1. PROCESS PROCEDURE FOR AQUEOUS CLEANING.

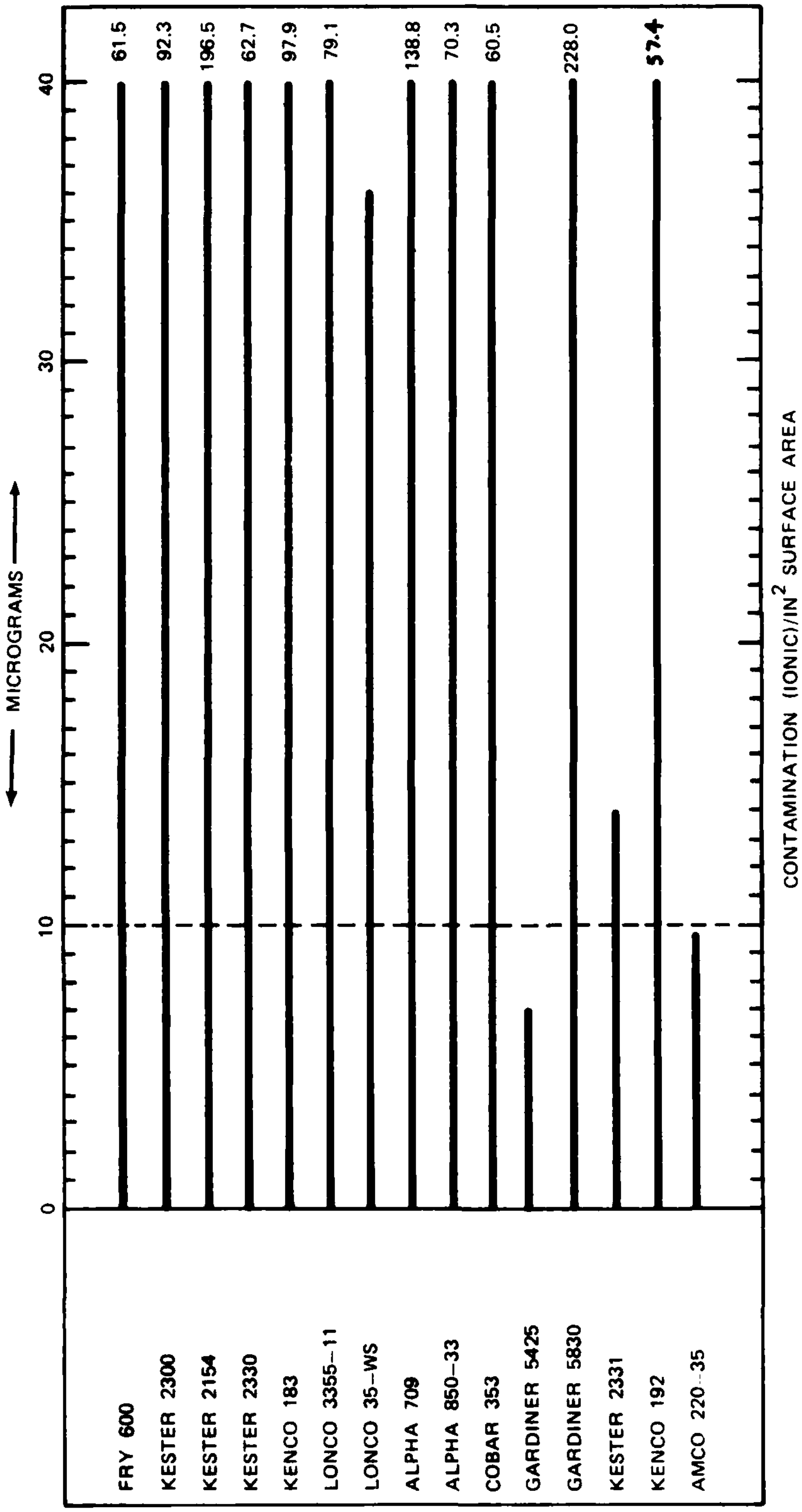

FIGURE V–2. NONROSIN FLUXES CLEANED WITH TAP WATER.

FLUX	$\mu g/in^2$	
	MEAN ($\bar{X}$)	STD. DEV.
FRY 600	61.5	32.0
KESTER 2300	92.3	45.51
KESTER 2154	196.5	N/A
KESTER 2330	62.7	N/A
KENCO 183	97.9	N/A
LONCO 3355-11	79.1	N/A
LONCO 35-WS	36.1	N/A
ALPHA 709	138.8	N/A
ALPHA 850-33	70.3	N/A
COBAR 353	60.5	N/A
GARDINER 5425	7.1	1.18
GARDINER 5830	228.0	N/A
KESTER 2331	14.0	1.88
KENCO 192	57.4	N/A
AMCO 220-35	9.56	2.58
SUPERIOR NO. 30	NT	NT
SUPERIOR NO. 45	NT	NT
XERSIN 2015	NT	NT
MULTICORE ESF 30	NT	NT
MULTICORE ESS 33	NT	NT

NT DENOTES NO TEST
NA DENOTES NOT AVAILABLE

FIGURE V-3. Non-Rosin Fluxes Cleaned with Tap Water, Mean and Standard Deviation.

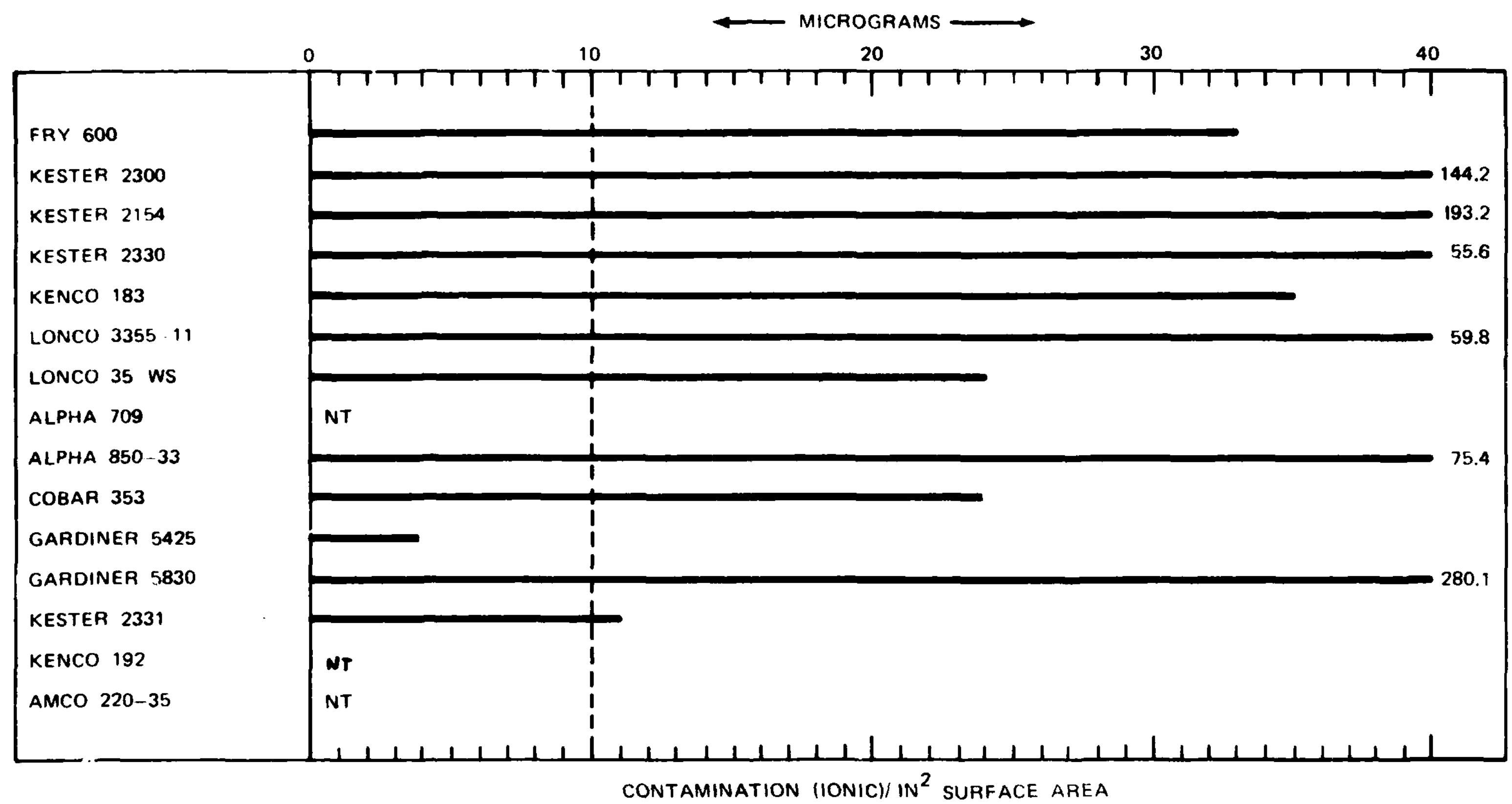

FIGURE V–4. NONROSIN FLUXES CLEANED WITH 2.5 X 10^5 OHM–cm WATER.

FLUX	μg/in^2	
	MEAN ($\bar{X}$)	STD. DEV.
FRY 600	33.1	N/A
KESTER 2300	144.2	N/A
KESTER 2154	193.2	N/A
KESTER 2330	55.6	N/A
KENCO 183	34.5	N/A
LONCO 3355-11	59.8	N/A
LONCO 35-WS	23.9	2.48
ALPHA 709	NT	NT
ALPHA 850-33	75.4	N/A
COBAR 353	23.5	4.93
GARDINER 5425	3.5	0.63
GARDINER 5830	280.1	N/A
KESTER 2331	10.4	1.41
KENCO 192	NT	NT
AMCO 220-35	NT	NT
SUPERIOR NO. 30	NT	NT
SUPERIOR NO. 45	NT	NT
XERSIN 2015	NT	NT
ESF 30	NT	NT
ESS 33	NT	NT

NT DENOTES NO TEST
NA DENOTES NOT AVAILABLE

FIGURE V-5. Non-Rosin Fluxes Cleaned with 2.5×10^5 ohm-cm Water, Mean and Standard Deviation.

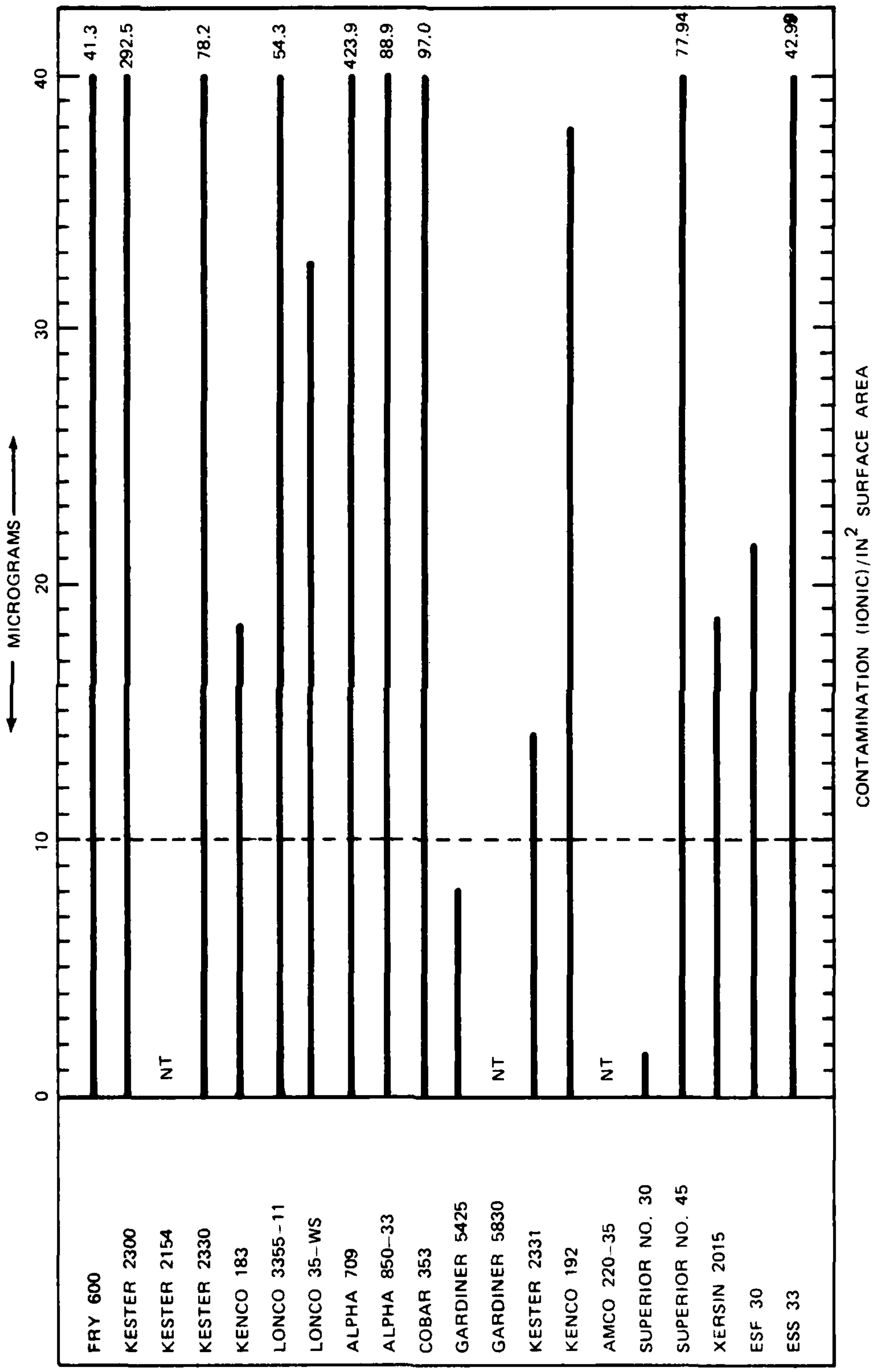

FIGURE V-6. NONROSIN FLUXES CLEANED WITH 2.5 X 10^6 OHM-cm WATER.

FLUX	μg/in²	
	MEAN ($\bar{X}$)	STD. DEV.
FRY 600	41.3	N/A
KESTER 2300	292.5	N/A
KESTER 2154	NT	NT
KESTER 2330	78.2	N/A
KENCO 183	18.2	N/A
LONCO 3355-11	54.3	N/A
LONCO 35-WS	32.8	N/A
ALPHA 709	423.9	N/A
ALPHA 850-33	88.9	N/A
COBAR 353	97.0	N/A
GARDINER 5425	7.9	0.74
GARDINER 5830	NT	N/A
KESTER 2331	14.0	1.71
KENCO 192	37.9	N/A
AMCO 220-35	NT	NT
SUPERIOR NO. 30	1.85	0.884
SUPERIOR NO. 45	77.94	13.86
XERSIN 2015	18.35	2.87
ESF 30	21.34	2.44
ESS 33	42.99	1.52

NT DENOTES NO TEST
NA DENOTES NOT AVAILABLE

FIGURE V-7. Non-Rosin Fluxes Cleaned with 2.5×10^6 ohm-cm Water, Mean and Standard Deviation.

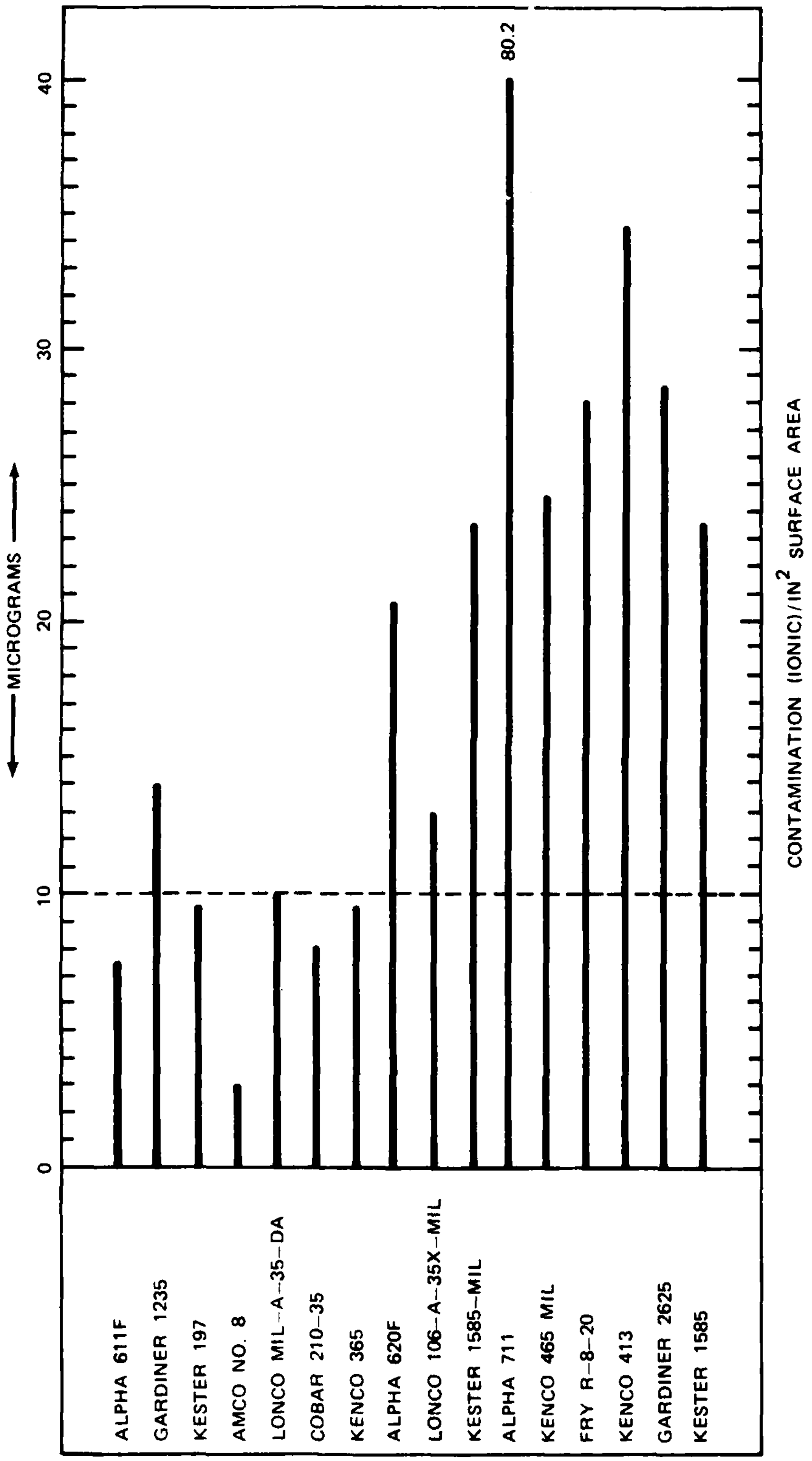

FIGURE V-8. RMA AND RA FLUXES CLEANED WITH 5% KESTER 5776.

FLUX	μg/in^2	
	MEAN ($\bar{X}$)	STD. DEV.
ALPHA 611F	7.24	4.31
GARDINER 1235	13.8	4.54
KESTER 197	9.43	3.49
AMCO NO. 8	2.92	0.41
LONCO MIL-A-35-DA	9.93	5.23
COBAR 210-35	8.03	2.08
KENCO 365	9.55	6.63
ALPHA 620F	20.7	2.29
LONCO 106-A-35X-MIL	12.5	0.85
KESTER 1585-MIL	23.6	4.06
ALPHA 711	80.2	4.72
KENCO 465-MIL	24.5	2.18
FRY R-8-20	27.9	12.3
KENCO 413	34.3	2.31
GARDINER 2625	28.3	4.25
KESTER 1585	23.6	1.82

FIGURE V-9. RMA and RA Fluxes Cleaned with 5% Kester 5776, Mean and Standard Deviation Values.

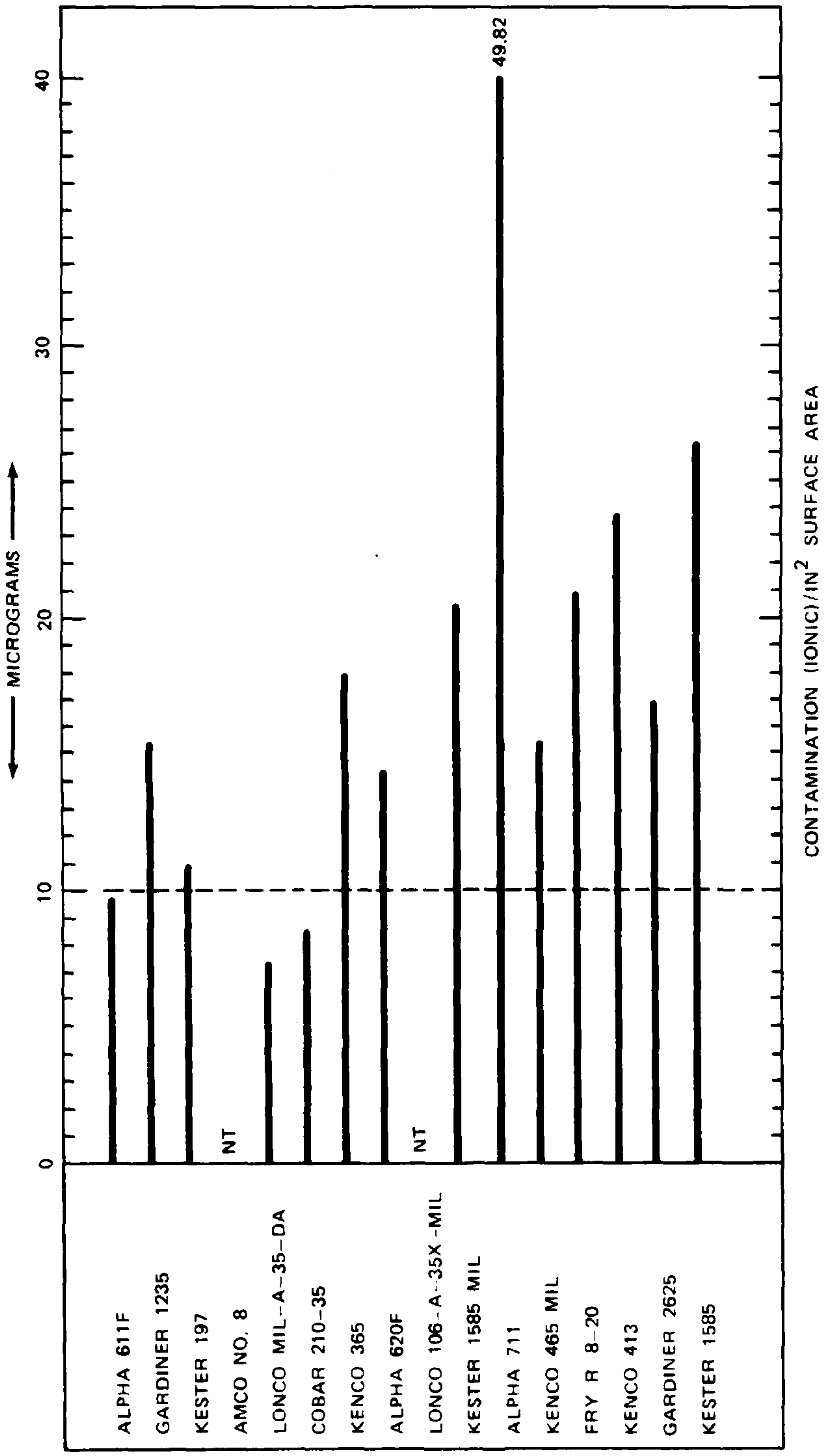

FIGURE V–10. RMA AND RA FLUXES CLEANED WITH 5% ALPHA 2100.

FLUX	μg/in^2	
	MEAN ($\bar{X}$)	STD. DEV.
ALPHA 611F	9.70	0.44
GARDINER 1235	15.09	2.57
KESTER 197	10.9	3.45
AMCO NO. 8	NT	NT
LONCO MIL-A-35-DA	7.28	0.65
COBAR 210-35	8.40	2.75
KENCO 365	17.92	5.80
ALPHA 620F	14.38	1.23
LONCO 106-A-35X-MIL	NT	NT
KESTER 1585-MIL	20.2	1.79
ALPHA 711	49.82	2.83
KENCO 465-MIL	15.17	0.79
FRY R-8-20	20.78	4.69
KENCO 413	23.41	3.11
GARDINER 2625	16.75	2.43
KESTER 1585	26.34	0.27

NT DENOTES NO TEST

FIGURE V-11. RMA and RA Fluxes Cleaned with 5% Alpha 2100, Mean and Standard Deviation Values.

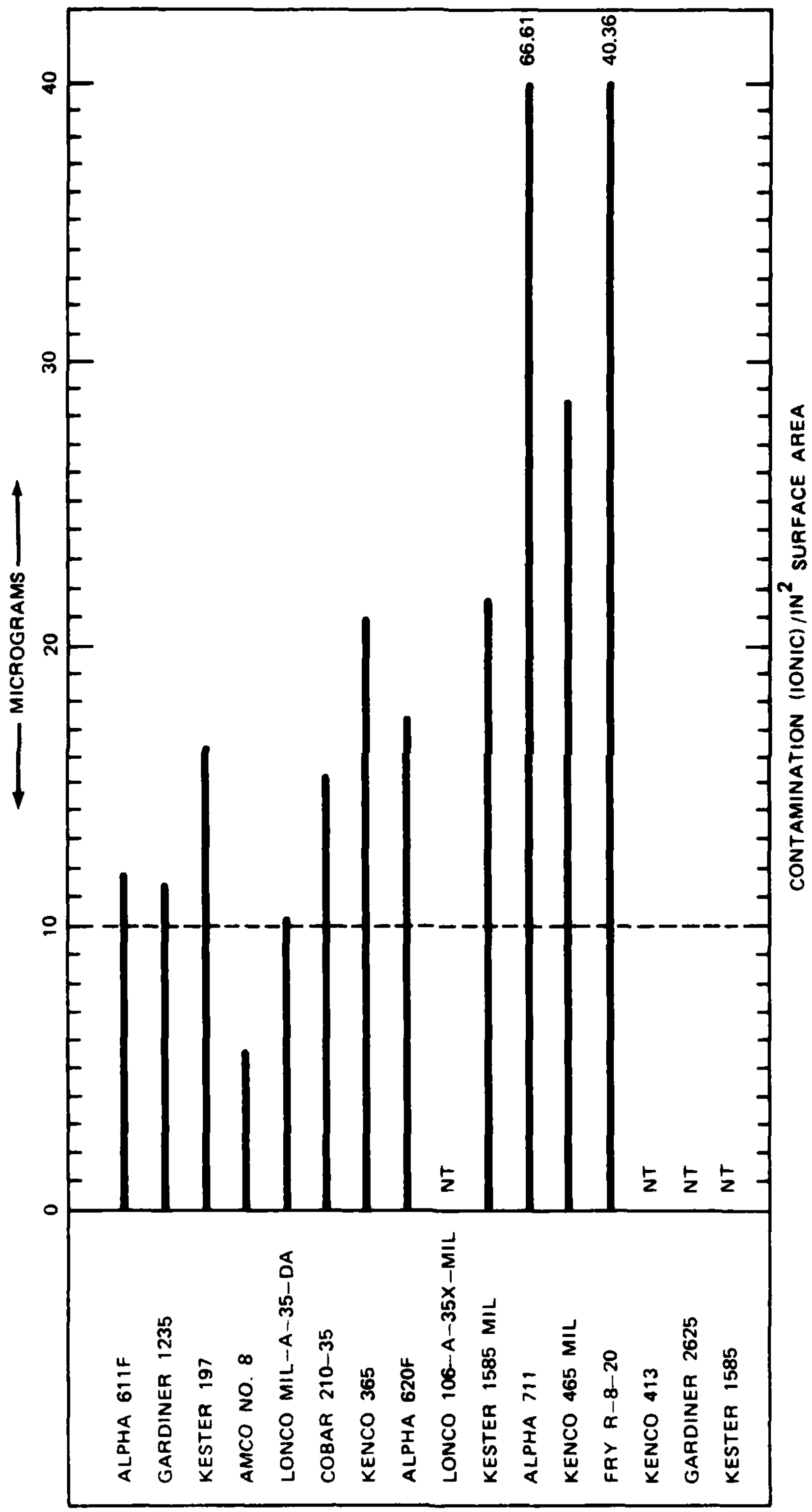

FIGURE V-12. RMA AND RA FLUXES CLEANED WITH 5% LONCO 520.

FLUX	μg/in²	
	MEAN ($\bar{X}$)	STD. DEV.
ALPHA 611F	11.99	3.79
GARDINER 1235	11.63	4.47
KESTER 197	16.25	2.06
AMCO NO. 8	5.61	0.51
LONCO MIL-A-35-DA	10.03	0.96
COBAR 210-35	15.34	1.14
KENCO 365	21.04	5.26
ALPHA 620F	17.51	0.18
LONCO 106-A-35X-MIL	NT	NT
KESTER 1585-MIL	21.51	1.52
ALPHA 711	66.61	7.38
KENCO 465-MIL	28.83	8.70
FRY R-8-20	40.36	1.19
KENCO 413	NT	NT
GARDINER 2625	NT	NT
KESTER 1585	NT	NT

NT DENOTES NO TEST

FIGURE V-13. RMA and RA Fluxes Cleaned with 5% Lonco 520, Mean and Standard Deviation Values.

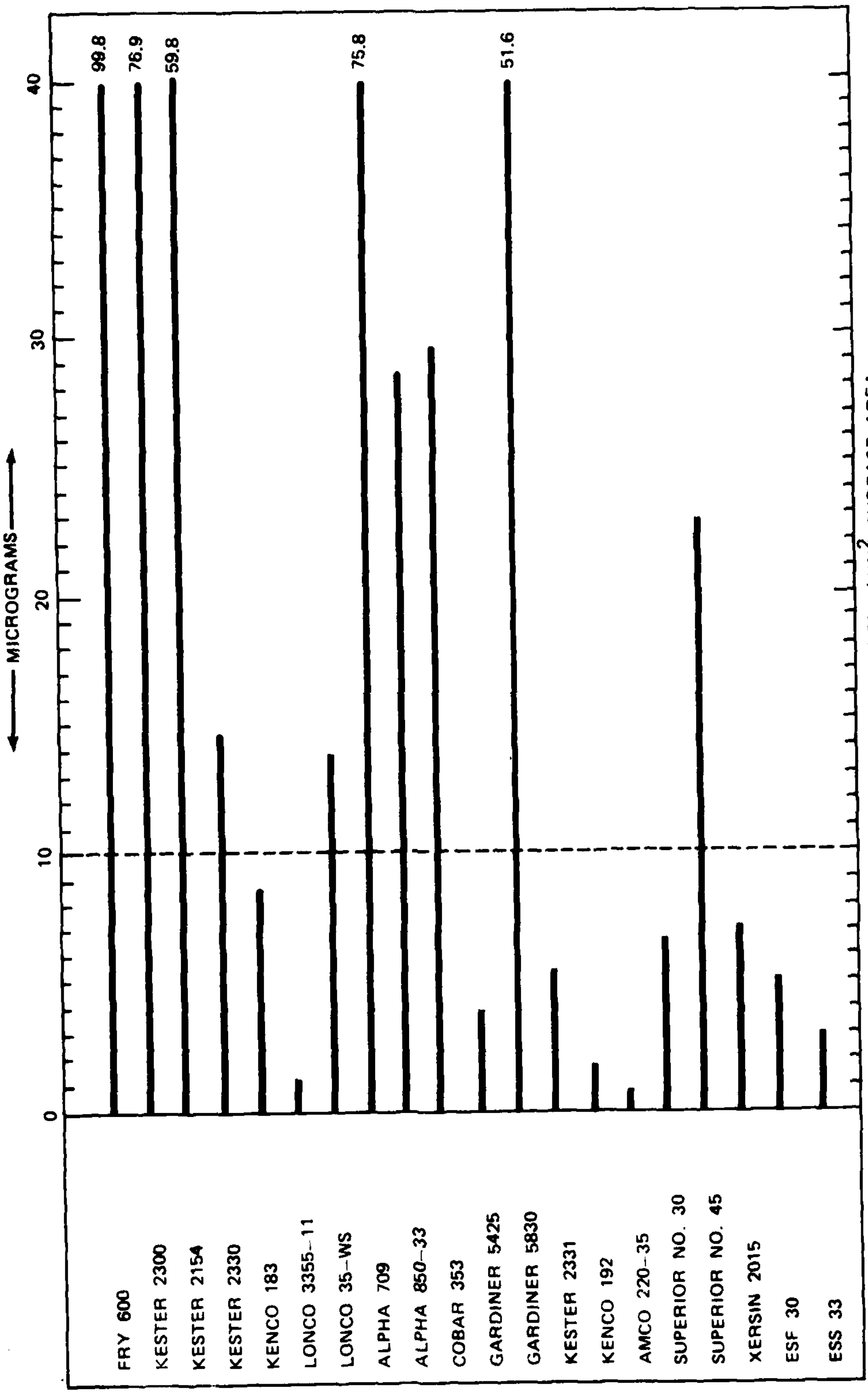

FIGURE V–14. NONROSIN FLUXES CLEANED WITH 5% KESTER 5776.

FLUX	µg/in^2	
	MEAN ($\bar{X}$)	STD. DEV.
FRY 600	99.8	3.53
KESTER 2300	76.9	12.9
KESTER 2154	59.8	23.8
KESTER 2330	14.5	2.06
KENCO 183	8.30	2.24
LONCO 3355-11	1.12	0.139
LONCO 35-WS	13.7	1.60
ALPHA 709	75.8	32.9
ALPHA 850-33	28.1	6.21
COBAR 353	29.1	1.15
GARDINER 5425	3.41	0.385
GARDINER 5830	51.6	3.94
KESTER 2331	5.19	3.62
KENCO 192	1.54	0.243
AMCO 220-35	0.553	0.25
SUPERIOR NO. 30	6.21	4.24
SUPERIOR NO. 45	22.53	5.76
XERSIN 2015	6.84	2.13
ESF 30	4.83	2.49
ESS 33	2.77	2.18

FIGURE V-15. Non-Rosin Fluxes Cleaned with 5% Kester 5776, Mean and Standard Deviation Values.

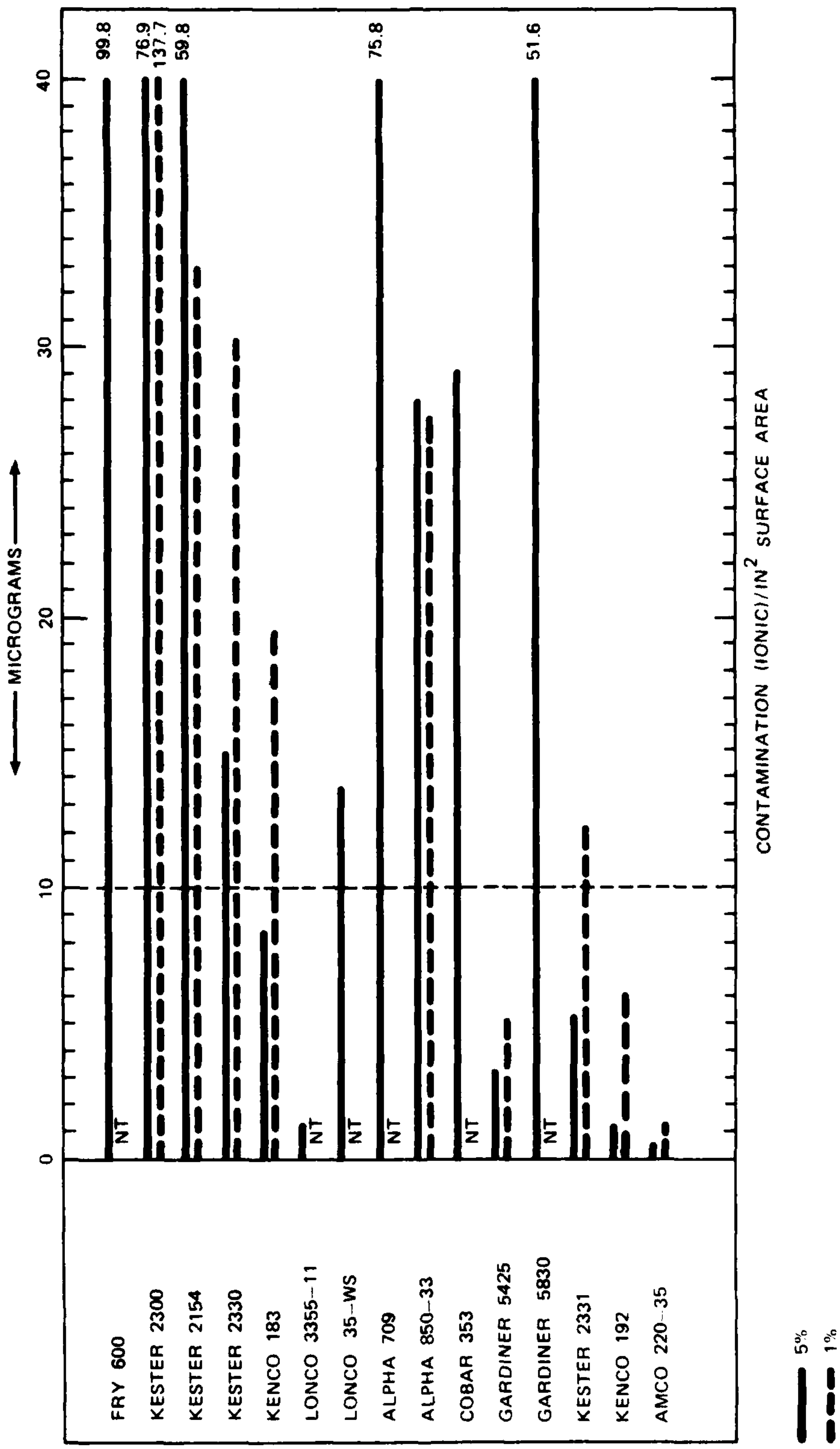

FIGURE V–16. 5% vs 1% KESTER 5776, NONROSIN FLUXES.

FLUX	$\mu g/in^2$	
	MEAN ($\bar{X}$)	STD. DEV.
FRY	NT	NT
KESTER 2300	137.7	7.6
KESTER 2154	33.43	1.56
KESTER 2330	30.5	3.6
KENCO 183	19.8	6.99
LONCO 3355-11	NT	NT
LONCO 35-WS	NT	NT
ALPHA 709	NT	NT
ALPHA 850-33	27.42	3.71
COBAR 353	NT	NT
GARDINER 5425	5.17	0.04
GARDINER 5830	NT	NT
KESTER 2331	12.15	4.85
KENCO 192	5.93	0.67
AMCO 220-35	1.87	1.24

FIGURE V-17. Non-Rosin Fluxes Cleaned with 1% Kester 5776, Mean and Standard Deviation Values.

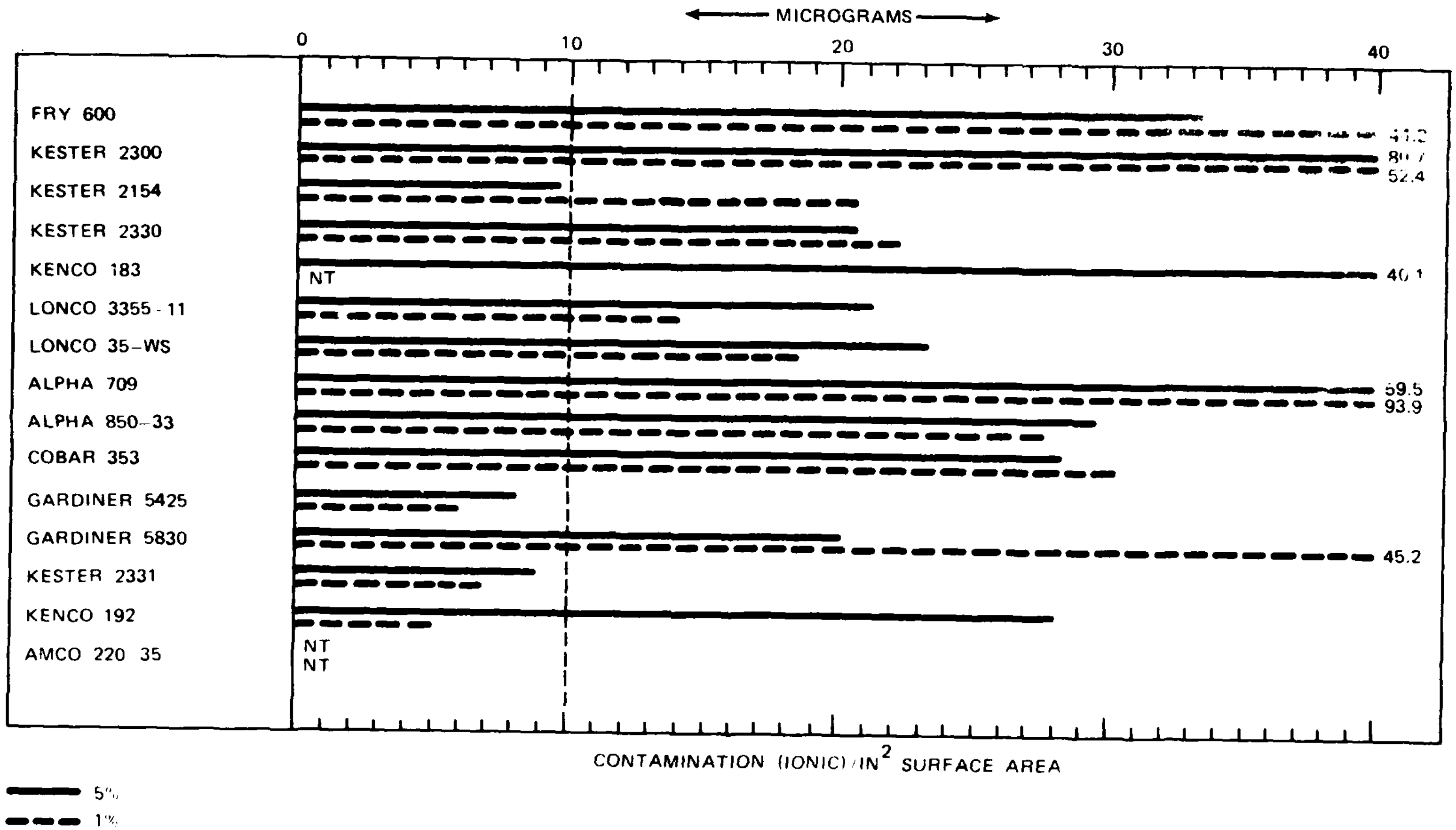

FIGURE V–18. 5% vs 1% ALPHA 2100, NONROSIN FLUXES.

FLUX	μg/in^2	
	MEAN ($\bar{X}$)	STD. DEV.
FRY 600	44.18	2.80
KESTER 2300	52.40	11.6
KESTER 2154	20.27	2.21
KESTER 2330	22.36	4.13
KENCO 183	NT	NT
LONCO 3355-11	14.0	1.27
LONCO 35-WS	17.99	3.30
ALPHA 709	93.88	36.3
ALPHA 850-33	27.74	5.54
COBAR 353	29.96	0.690
GARDINER 5425	5.60	0.701
GARDINER 5830	45.23	3.76
KESTER 2331	6.65	0.99
KENCO 192	4.87	1.03
AMCO 220-35	NT	NT

NT DENOTES NO TEST

FIGURE V-19. Non-Rosin Fluxes Cleaned with 1% Alpha 2100, Mean and Standard Deviation Values.

FLUX	µg/in²	
	MEAN ($\bar{X}$)	STD. DEV.
FRY 600	33.57	1.48
KESTER 2300	80.71	N/A
KESTER 2154	9.71	0.812
KESTER 2330	20.8	5.29
KENCO 183	40.1	3.22
LONCO 3355-11	21.52	2.74
LONCO 35-WS	23.20	3.62
ALPHA 709	59.47	11.35
ALPHA 850-33	29.75	1.71
COBAR 353	28.23	2.62
GARDINER 5425	7.65	0.370
GARDINER 5830	19.3	0.230
KESTER 2331	8.62	0.330
KENCO 192	28.04	0.788
AMCO 220-35	NT	NT

NT DENOTES NO TEST
N/A DENOTES NOT AVAILABLE

FIGURE V-20. Non-Rosin Fluxes Cleaned with 5% Alpha 2100, Mean and Standard Deviation Values.

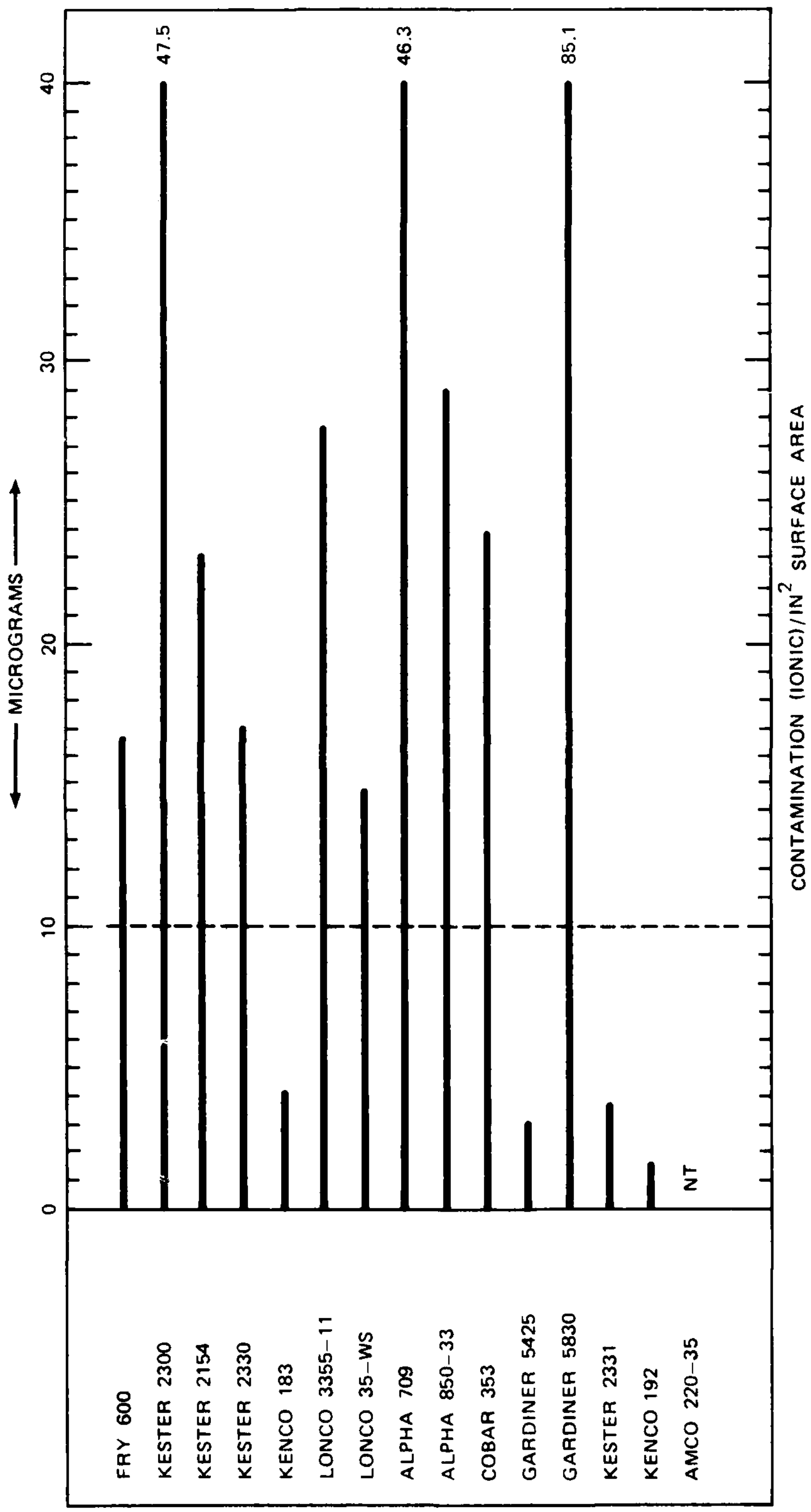

FIGURE V-21. 1% LONCO 520, NONROSIN FLUXES.

FLUX	$\mu g/in^2$	
	MEAN ($\bar{X}$)	STD. DEV.
FRY 600	16.8	9.13
KESTER 2300	47.5	2.71
KESTER 2154	23.3	1.97
KESTER 2330	17.3	1.28
KENCO 183	4.14	2.30
LONCO 3355-11	27.6	18.2
LONCO 35-WS	14.77	2.50
ALPHA 709	46.3	40.0
ALPHA 850-33	29.23	7.60
COBAR 353	24.0	1.68
GARDINER 5425	3.20	0.47
GARDINER 5830	85.07	N/A
KESTER 2331	3.83	0.20
KENCO 192	1.73	0.36
AMCO 220-35	NT	NT

NT DENOTES NO TEST
N/A DENOTES NOT AVAILABLE

FIGURE V-22. Non-Rosin Fluxes Cleaned with 1% Lonco 520, Mean and Standard Deviation Values.

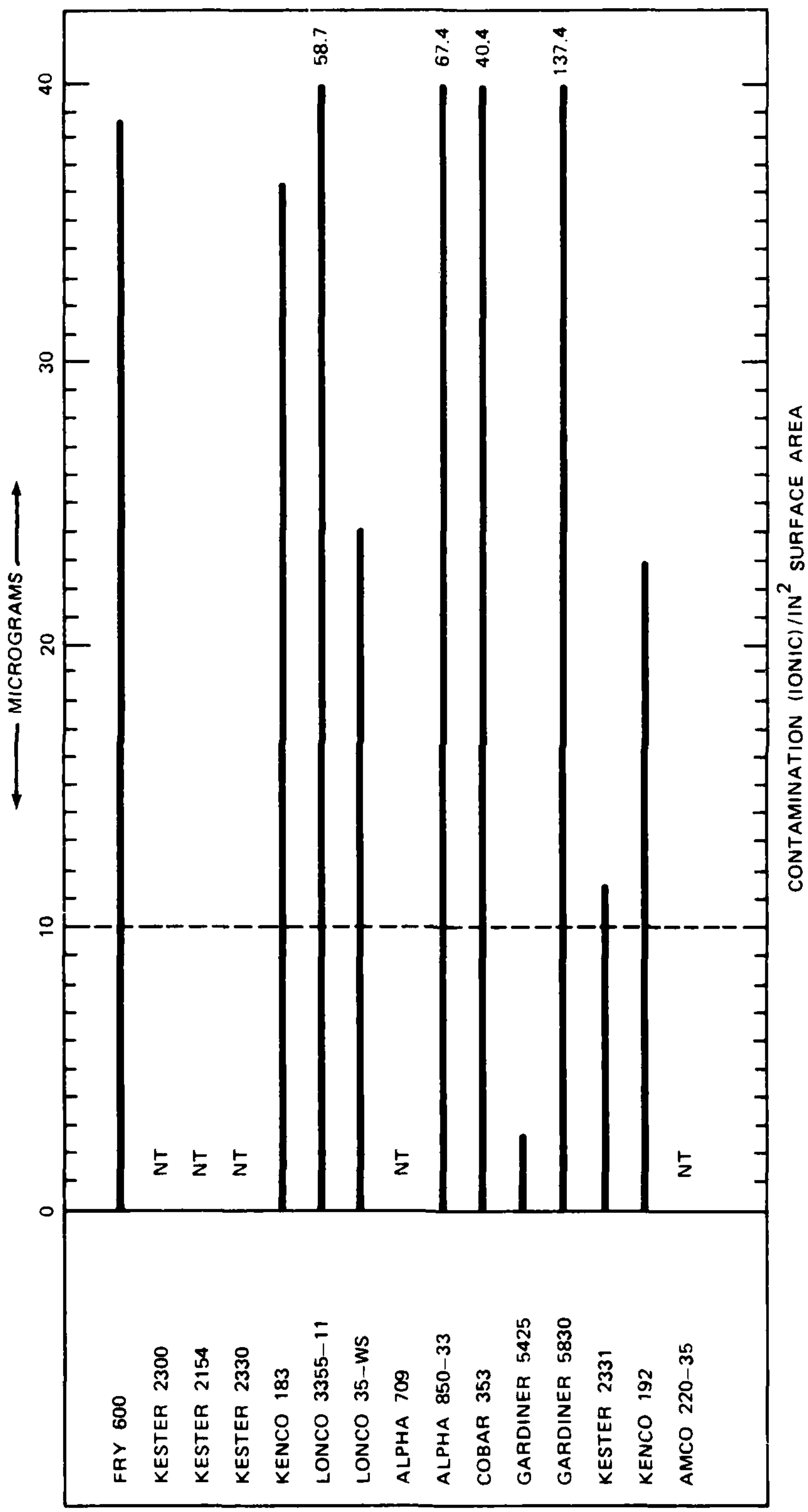

FIGURE V–23. 1% GARDINER 4800, NONROSIN FLUXES.

VI. COMBINATION CLEANING

A test was conducted on the effectiveness of a combination of solvent and aqueous cleaning. Eight fluxes were selected for this special test: three RMA, three RA, and two non-rosin fluxes. Figure VI-1 illustrates the test procedure. Four sample boards were wave soldered for each flux. After wave soldering, all samples were cleaned in a vapor degreaser of Freon TE using a 2-1-1 cycle. One board was then cleanliness tested to establish a baseline value for solvent cleaning alone. The other three boards were cleaned in the aqueous cleaner using only deionized water and then cleanliness tested.

Figures VI-2 and VI-3 show that the fluxes were significantly cleaner after the deionized water rinse than with the solvent cleaning alone. All but one flux passed ionic cleanliness testing with combination cleaning. The non-rosin fluxes did clean better with detergent cleaning than with combination cleaning. This is due to the fact that non-rosin fluxes were not designed to be cleaned with solvents.

The combination of a solvent cleaning followed by a deionized water rinse proved to be a very effective method for removing ionic contamination. The rosin fluxed samples were all cleaned appreciably better with the combination cleaning than with the solvent degreasing alone. The non-rosin fluxes cleaned well, but better results were obtained in a detergent cleaning process than in the combination process. Possibly, if the order of the combination cleaning was reversed, aqueous first then solvent, the non-rosin fluxes would have cleaned better.

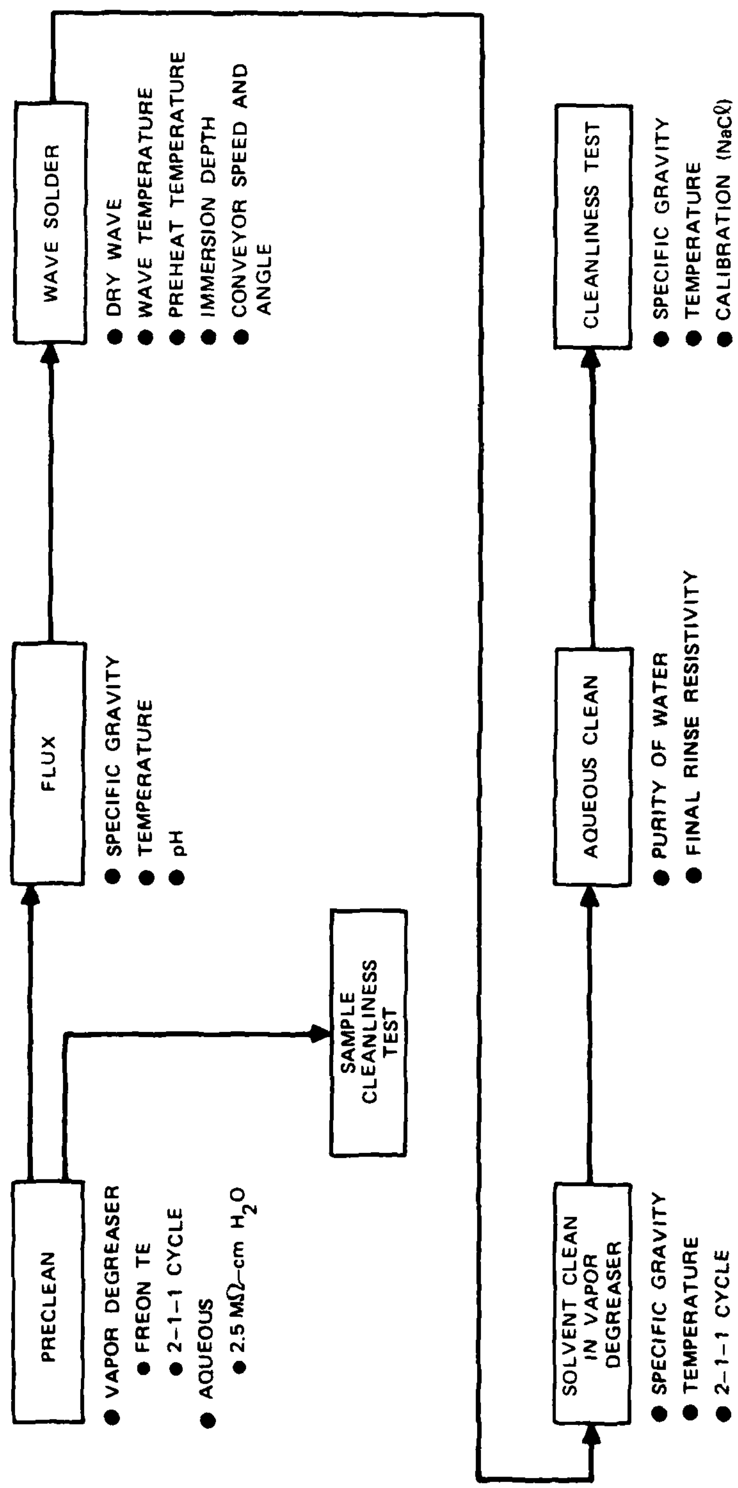

FIGURE VI-1. PROCESS PROCEDURE FOR COMBINATION CLEANING.

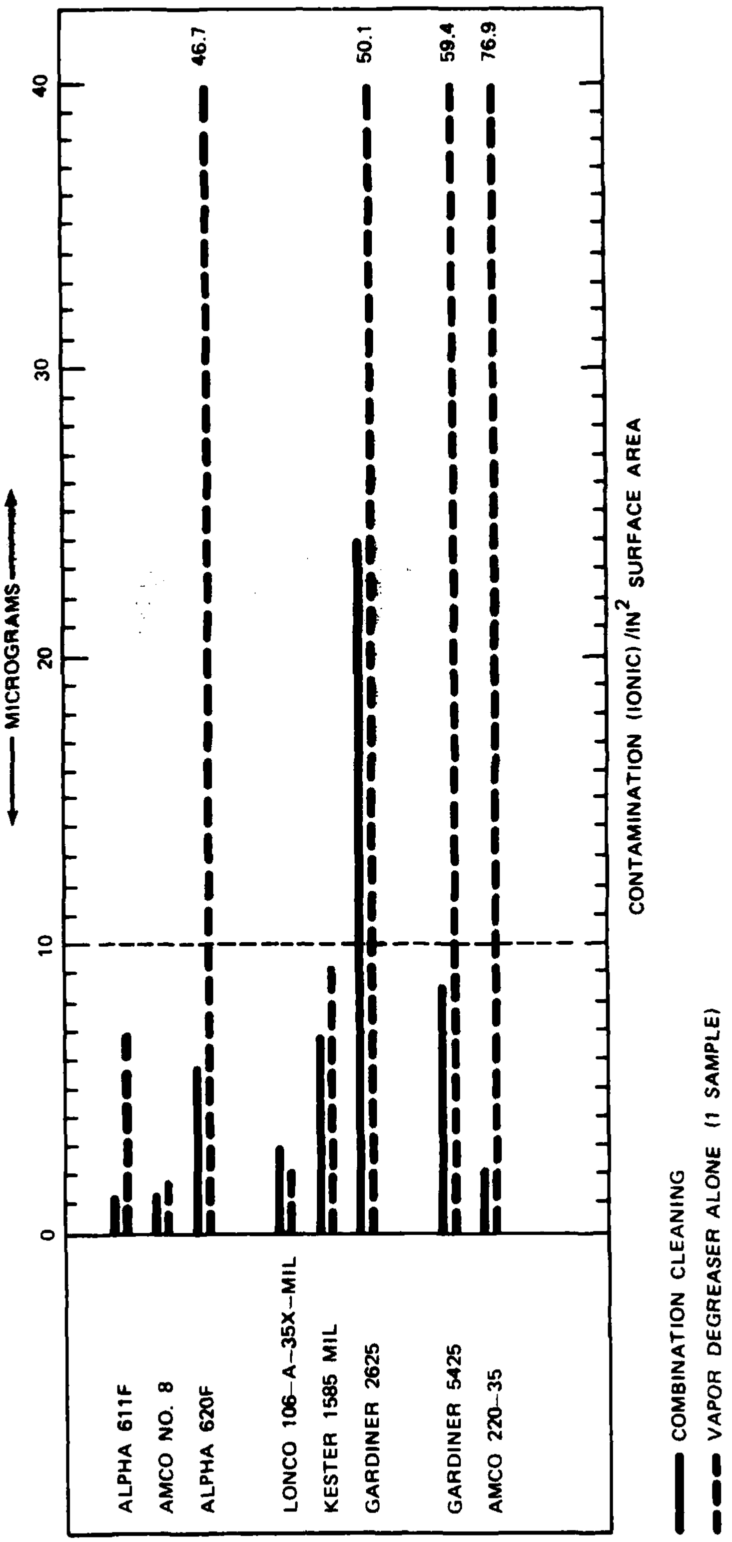

FIGURE VI-2. COMBINATION CLEANING, ALL FLUX TYPES.

FLUX	ONLY VAPOR DEGREASER ($\mu g/in^2$)	MEAN $\bar{X}$ ($\mu g/in^2$)	STD DEV ($\mu g/in^2$)
ALPHA 611F	6.73	1.39	0.972
AMCO NO. 8	1.63	1.26	0.605
ALPHA 620F	46.7	5.60	1.85
LONCO 106-A-35X-MIL	1.95	2.91	1.16
KESTER 1585-MIL	9.65	6.28	4.48
GARDINER 2625	50.1	22.53	10.7
GARDINER 5425	59.40	7.92	1.07
AMCO 220-35	76.91	2.07	2.08

FIGURE VI-3. Combination Cleaning, Mean and Standard Deviation Values.

VII. INSULATION RESISTANCE

Insulation resistance tests were conducted to determine if the ionic cleanliness test, by itself, was a sufficient method of testing for contaminants on the circuit board. Since the Ionograph tests only for the ionic contamination on the board, there was concern about the non-ionic contamination on the circuit boards that was undetectable. Insulation resistance was a method that could be used to detect the effects of both ionic and non-ionic contaminants.

The fluxes that had tested ionically cleanest when processed in a 5% Kester 5776 detergent solution, were chosen as the insulation resistance candidates. Three RA fluxes, four RMA fluxes, and six non-rosin fluxes were tested.

Each flux was processed in the same manner as the 5% Kester 5776 flux cleaning tests (Figure VII-1). Four samples of each flux were processed in this manner. After aqueous cleaning, one of the samples was ionic cleanliness tested to verify that the level of ionic contamination was in agreement with earlier tests. The other three samples were moisture/temperature cycled for insulation resistance testing.

The moisture/temperature cycling test used was a modified version of MIL-STD-202, Method 106E. Figure VII-2 illustrates the modified method. Samples began the cycle at Hour 0 and continued for 10 days. A Blue M Humidity Chamber Model No. FR-256PC-1 was used to control the moisture/temperature cycling.

Insulation resistance readings were taken at Hour 0 and Hour 6 of each cycle. Readings were also taken before cycling had begun on Day 0 and 1-1/2 hours after completion of the 10th cycle while at ambient

temperature and humidity. One final set of resistance measurements were taken either 1 or 3 days later, again at ambient conditions. The final measurement was taken to determine whether any resistance changes had occurred while the samples remained at ambient conditions.

Measurements were taken on the unsoldered side of the board on the 6.5 mil comb pattern after an electrification time of 1 minute, using 100 VDC. Measurements were made on a GenRad Megohm Bridge Type 1644 with a 1×10^{15} ohms upper limit. There was no applied voltage on the samples except during the 1 minute of electrification.

A special connector system with a series of ten edge connectors wired into an open-sided frame was designed. This system was used as a means to eliminate contaminants from sources other than the flux and cleaning operation. A diagram of the connector system is shown in Figure VII-3. Forty-four pin gold-tipped edge connectors were used to connect the sample boards into the system.

The edge connector method was chosen over hard wiring for several reasons:

1. contamination from hard-wiring was eliminated;
2. effects due to conformal coating after hard-wiring were eliminated;
3. variations in hard-wiring connections were eliminated; and
4. preparation time was reduced for the large volume of fluxes tested.

The connectors were thoroughly cleaned with isopropanol between tests in order to avoid cross-contamination from earlier tests. The test method chosen and the procedures taken were designed to introduce the least amount of variables into the insulation resistance testing. Samples were not conformally coated.

The resistance of the open connector system was measured each time sample resistance was measured. The system never had a resistance less than 6×10^{11} ohms. A clean unfluxed sample board was cycled along with the fluxed boards as a standard. The standard board was used to verify that the connector system did not influence the resistance readings of the fluxed samples and to give a value to which sample readings could be compared. The standard board never had a resistance lower than 2.6×10^{7} ohms.

Criteria for the failure of a flux involved three items:

1. Resistance of more than an order of magnitude lower than the standard board;
2. No recovery of high resistance upon cycling to the low temperature phase;
3. Resistance ever drops below 2×10^{6} ohms. This minimum resistance was calculated using the method described by Naval Avionics Center in the report "Deleterious Effects of MIL-F-14256, Type RA, Fluxes on Printed Wiring Boards," TR-2253, dated 31 January 1979. This value is related to the MIL-P-55110 resistance of 500 megohms. The true minimum resistance value was determined to be 1.8×10^{6} ohms but was rounded up to 2×10^{6} ohms for ease of comparison.

If two or more of the samples exhibited any of these failure criteria, the flux was considered to have failed the insulation resistance moisture/temperature cycling test.

Four RMA fluxes were tested in the insulation resistance tests. Each one of them had resistance values higher than the standard (Figures VII-4, VII-5, VII-6 and VII-7). This is probably due to the rosin--it is an insulator, so it tests ionically clean and provides some protection to the comb pattern because it is hydrophobic. The standard

board did not have the benefit of this protection so it had lower resistance values than the rosin-fluxed samples.

The RMA fluxes passed the ionic testing and the insulation resistance testing, but generally did not appear clean or free from residue when examined after moisture/temperature cycling. The exception was Alpha 611F, which remained clean and shiny. Amco No. 8 samples showed a slight white residue on the edges of the comb bar. Small spots of flux were visible on the Kester 197 samples and large areas of flux were visible on the Cobar 210-35 samples.

Three RA fluxes were insulation resistance tested. Like the RMA fluxes, the resistance values were higher than the unfluxed standard board, thus, the RA fluxes passed the insulation resistance testing (Figures VII-8, VII-9, and VII-10). Conversely, each of the RA fluxes tested failed the ionic testing. In addition, the samples did not appear clean and free from residue after the moisture/temperature cycling. The Lonco 106-A-35X-MIL samples had small areas of flux on them and both the Kester 1585-MIL and the Kenco 465-MIL samples showed large areas of flux on them after cycling. The Kenco 465-MIL also had a dull appearance of the solder.

All of the non-rosin fluxes failed the insulation resistance testing because two or more samples from each flux exhibited one or more of the failure criteria (Figures VII-11, VII-12, VII-13, VII-14, VII-15, and VII-16). Each of the six fluxes passed the ionic testing, yet failed the insulation resistance testing. In addition, the appearance of several of the fluxed samples was unsatisfactory.

Kenco 192 samples (Figure VII-11) had resistance values more than an order of magnitude lower than the standard unfluxed sample. One sample also had a resistance lower than the 2×10^6 ohms minimum resistance value allowed. Examination of the samples after cycling showed

dull solder and brown discoloration of the metal on the top side of the board.

Amco 220-35 samples (Figure VII-12) failed insulation resistance testing because each of the three samples were more than an order of magnitude lower than the standard. After cycling, the samples appeared clean and shiny.

Gardiner 5425 (Figure VII-13) failed resistance testing because each of the three samples showed two or more of the failure criteria. Each sample had a resistance of more than an order of magnitude lower than the standard throughout the testing. Also, all resistance values were lower than the 2 x 10^6 ohms minimum resistance value. Samples A and C also failed because they did not recover to the higher resistance during the low temperature phase of the cycle (Sample A--Day 7, 9, and 10; Sample C--Day 9). Examination of the samples after cycling showed small burned spots on the circuitry of Samples A and C and also a brown discoloration of the metal.

Lonco 3355-11 (Figure VII-14) failed insulation resistance testing because there was a dramatic decrease in resistance during the first cycle. A resistance drop such as this could cause a catastrophic failure in a piece of military hardware. Although the samples had sharp decreases in resistance, they did not go below the allowed minimum resistance (Sample A--3.5 x 10^7 ohms, Sample B--1.3 x 10^7, Sample C--5.0 x 10^7 ohms). The samples behaved satisfactorily for the remainder of the test. After cycling, the samples appeared shiny and clean.

Kester 2331 (Figure VII-15) samples had resistances at a level of and lower than the 2 x 10^6 ohms minimum allowed value. This flux, therefore, failed insulation resistance testing. After cycling, the samples showed dull-looking solder.

Kenco 183 (Figure VII-16) had several sharp drops in resistance to levels near the failure point during the first days of the cycling. The samples appeared clean and shiny after cycling.

The RMA fluxes passed the insulation resistance testing and the ionic cleanliness testing, while the RA fluxes passed only the resistance testing. The non-rosin fluxes passed ionic testing but failed the insulation resistance testing. This demonstrates that neither the ionic cleanliness test, as used in this study, nor the insulation resistance test, by itself, is an adequate measure of the effects a flux has on a printed wiring board. A pass on both tests gives an indication that a flux is less likely to affect the performance of a board.

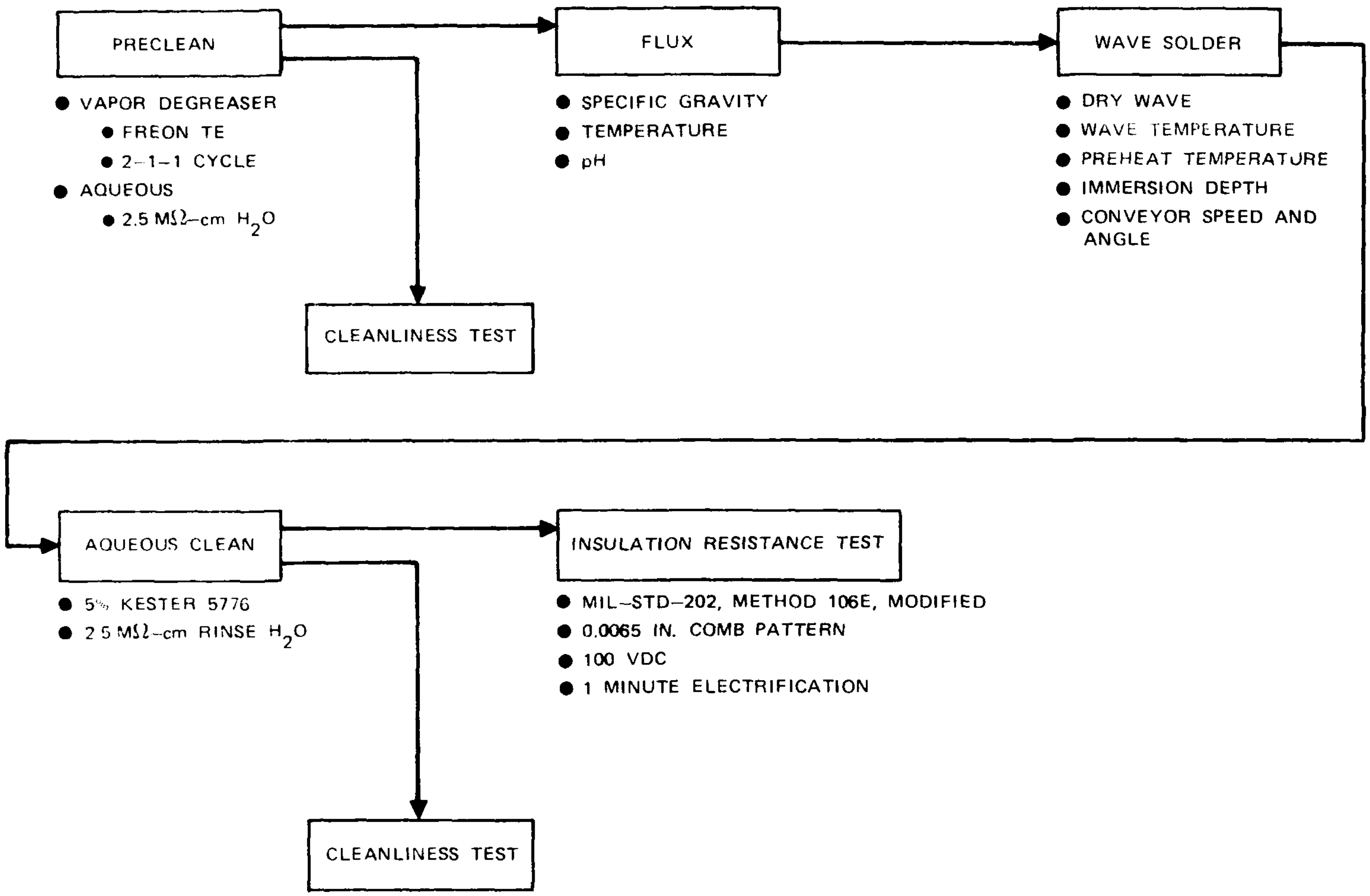

FIGURE VII-1. PROCESS PROCEDURE FOR INSULATION RESISTANCE TESTING.

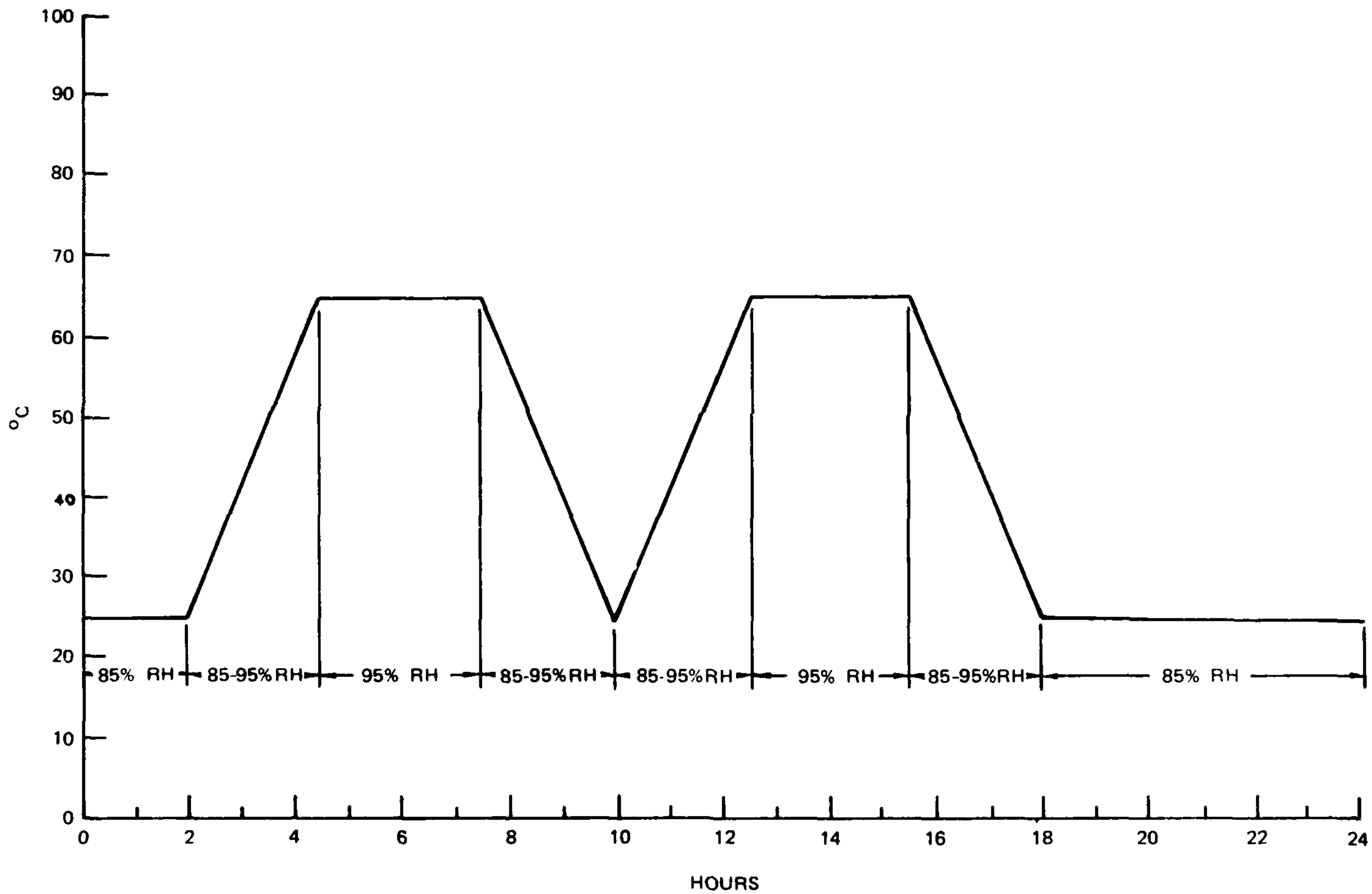

FIGURE VII-2. MODIFIED VERSION, MIL-STD-202, METHOD 106E.

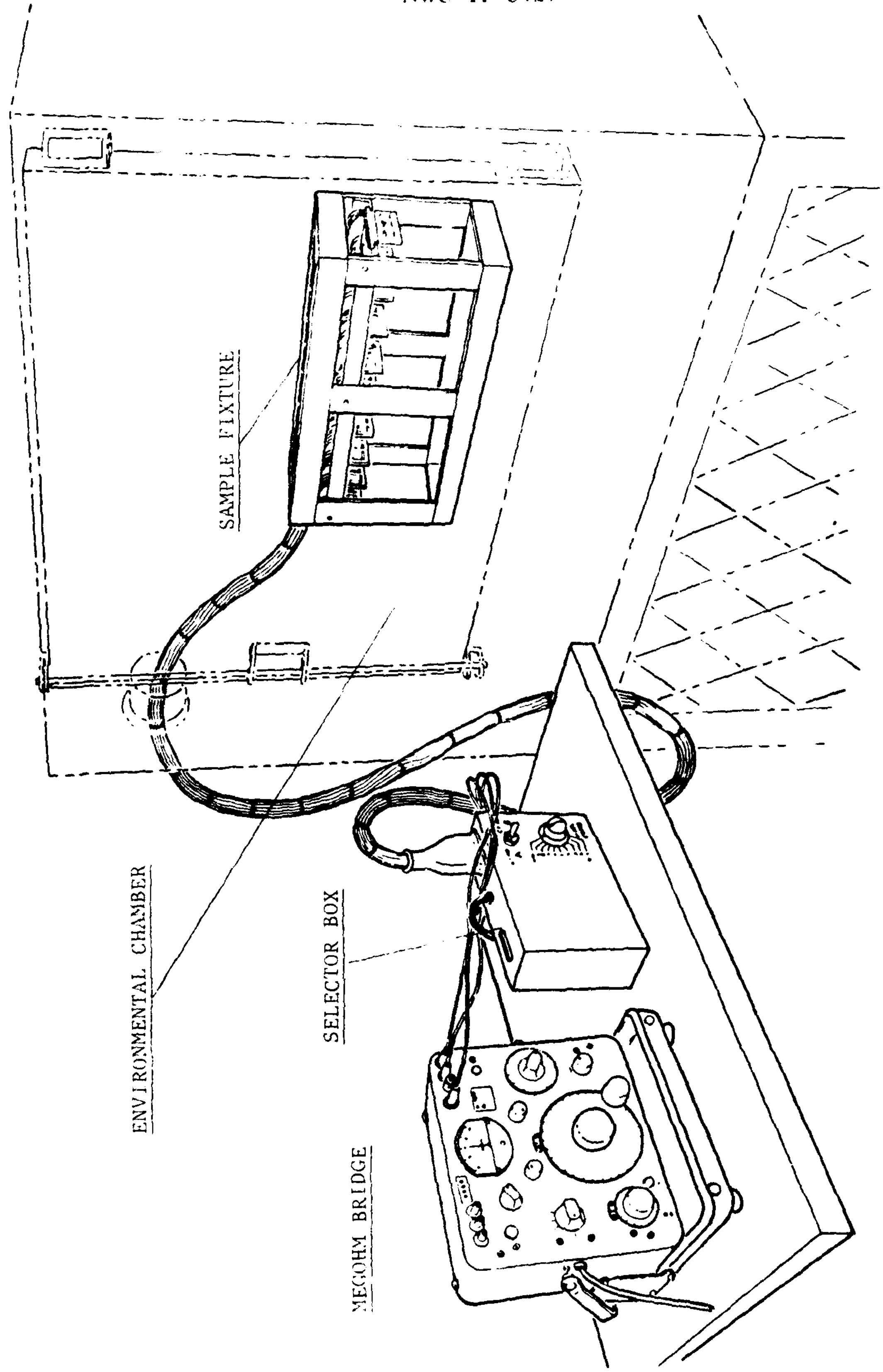

Figure VII-3. Connector System

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	7.3×10^{12}	2.1×10^{12}	3.8×10^{12}	6.2×10^{12}
1	25	7.8×10^{7}	1.2×10^{11}	9.8×10^{8}	1.9×10^{10}
1	65	2.4×10^{7}	3.9×10^{9}	1.2×10^{8}	1.9×10^{9}
2	25	3.0×10^{8}	3.1×10^{11}	2.7×10^{9}	4.6×10^{10}
2	65	3.5×10^{7}	4.5×10^{9}	2.4×10^{8}	1.8×10^{9}
3	25	4.4×10^{8}	3.3×10^{11}	6.0×10^{9}	6.2×10^{10}
3	65	4.7×10^{7}	2.2×10^{9}	3.8×10^{8}	2.1×10^{9}
4	25	3.5×10^{8}	2.4×10^{11}	8.7×10^{9}	3.7×10^{9}
4	65	3.2×10^{7}	5.7×10^{8}	5.7×10^{8}	5.4×10^{8}
5	25	2.9×10^{8}	1.4×10^{11}	8.8×10^{9}	7.3×10^{9}
5	65	4.4×10^{7}	1.4×10^{9}	7.3×10^{8}	9.6×10^{8}
6	25	4.6×10^{8}	1.7×10^{11}	1.7×10^{10}	1.15×10^{10}
6	65	4.5×10^{7}	2.3×10^{9}	9.3×10^{8}	7.9×10^{8}
7	25	4.8×10^{8}	1.4×10^{11}	2.7×10^{10}	2.2×10^{10}
7	65	5.2×10^{7}	3.1×10^{9}	1.3×10^{9}	9.6×10^{8}
8	25	6.9×10^{8}	1.9×10^{11}	4.2×10^{10}	2.7×10^{10}
8	65	3.6×10^{7}	2.2×10^{9}	1.4×10^{9}	9.2×10^{8}
9	25	7.5×10^{8}	1.7×10^{11}	4.6×10^{10}	3.1×10^{10}
9	65	3.9×10^{7}	3.8×10^{9}	1.6×10^{9}	1.1×10^{9}
10	25	7.5×10^{8}	2.0×10^{11}	5.4×10^{10}	3.1×10^{10}
10	65	3.5×10^{7}	2.8×10^{9}	1.6×10^{9}	1.0×10^{9}
FINAL	AMBIENT	1.6×10^{11}	3.6×10^{11}	3.9×10^{11}	4.0×10^{11}
3 DAYS LATER	AMBIENT	7.0×10^{10}	1.2×10^{11}	1.5×10^{11}	2.4×10^{11}

FIGURE VII-4. Insulation Resistance Values Alpha 611F.

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	1.38×10^{11}	1.28×10^{11}	1.36×10^{11}	1.36×10^{11}
INITIAL	AMBIENT	4.8×10^{7}	1.1×10^{8}	7.8×10^{7}	6.1×10^{8}
1	25	3.9×10^{9}	5.2×10^{9}	1.6×10^{11}	1.8×10^{11}
1	65	4.3×10^{7}	6.2×10^{7}	3.6×10^{7}	2.5×10^{8}
2	25	4.4×10^{9}	1.2×10^{10}	1.2×10^{11}	2.1×10^{11}
2	65	5.7×10^{7}	6.4×10^{7}	2.7×10^{7}	2.4×10^{8}
3	25	5.4×10^{9}	1.1×10^{10}	6.6×10^{10}	1.5×10^{11}
3	65	7.1×10^{7}	9.7×10^{7}	3.4×10^{7}	2.3×10^{8}
4	25	8.4×10^{9}	1.3×10^{10}	5.6×10^{10}	2.5×10^{11}
4	65	6.7×10^{7}	1.0×10^{8}	3.1×10^{7}	7.4×10^{7}
5	25	6.3×10^{9}	1.5×10^{10}	3.1×10^{10}	2.7×10^{11}
5	65	7.8×10^{7}	1.0×10^{8}	3.1×10^{7}	1.7×10^{8}
6	25	5.9×10^{9}	1.4×10^{10}	3.3×10^{10}	2.1×10^{11}
6	65	8.6×10^{7}	1.1×10^{8}	4.6×10^{7}	2.7×10^{8}
7	25	6.4×10^{9}	9.7×10^{9}	2.0×10^{10}	1.7×10^{11}
7	65	9.8×10^{7}	1.2×10^{8}	5.5×10^{7}	3.6×10^{8}
8	25	6.5×10^{9}	8.1×10^{9}	2.6×10^{10}	1.1×10^{11}
8	65	8.0×10^{7}	1.2×10^{8}	4.8×10^{7}	2.8×10^{8}
9	25	4.8×10^{9}	6.8×10^{9}	1.3×10^{10}	7.2×10^{10}
9	65	1.0×10^{8}	1.3×10^{8}	7.6×10^{7}	2.1×10^{8}
10	25	8.0×10^{9}	8.2×10^{9}	2.6×10^{10}	6.6×10^{10}
10	65	7.2×10^{7}	1.2×10^{8}	9.0×10^{7}	1.7×10^{8}
FINAL	AMBIENT	8.3×10^{8}	2.5×10^{11}	3.9×10^{10}	1.0×10^{11}

FIGURE VII-5. Insulation Resistance Values Kester 197.

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	7.0×10^{12}	4.8×10^{12}	2.9×10^{12}	3.5×10^{12}
1	25	5.6×10^{7}	3.8×10^{9}	9.3×10^{8}	1.3×10^{9}
1	65	4.2×10^{7}	4.7×10^{8}	8.7×10^{7}	4.3×10^{8}
2	25	2.8×10^{8}	2.7×10^{10}	3.0×10^{9}	3.0×10^{9}
2	65	9.0×10^{7}	8.7×10^{8}	2.8×10^{8}	1.2×10^{9}
3	25	4.7×10^{8}	1.4×10^{10}	8.1×10^{9}	5.1×10^{9}
3	65	9.6×10^{7}	1.1×10^{9}	5.7×10^{8}	1.8×10^{9}
4	25	3.7×10^{8}	8.5×10^{9}	1.1×10^{10}	6.2×10^{9}
4	65	8.0×10^{7}	1.2×10^{9}	6.4×10^{8}	1.3×10^{9}
5	25	3.3×10^{8}	7.3×10^{9}	8.8×10^{9}	8.9×10^{9}
5	65	8.3×10^{7}	1.1×10^{9}	8.5×10^{8}	9.0×10^{8}
6	25	3.6×10^{8}	1.2×10^{10}	2.1×10^{10}	9.3×10^{9}
6	65	1.1×10^{8}	1.3×10^{9}	1.1×10^{9}	2.3×10^{9}
7	25	4.8×10^{8}	1.7×10^{10}	1.7×10^{10}	6.9×10^{9}
7	65	1.2×10^{8}	2.3×10^{9}	1.4×10^{9}	2.4×10^{9}
8	25	5.1×10^{8}	4.5×10^{10}	3.2×10^{10}	1.2×10^{10}
8	65	9.4×10^{7}	1.2×10^{9}	1.4×10^{9}	1.2×10^{9}
9	25	5.8×10^{8}	7.1×10^{10}	5.7×10^{10}	8.1×10^{9}
9	65	1.2×10^{8}	2.1×10^{9}	1.7×10^{9}	2.7×10^{9}
10	25	6.1×10^{8}	5.3×10^{10}	6.6×10^{10}	3.5×10^{10}
10	65	8.9×10^{7}	1.5×10^{9}	1.7×10^{9}	1.3×10^{9}
FINAL	AMBIENT	1.4×10^{11}	3.8×10^{11}	3.5×10^{11}	4.1×10^{11}
3 DAYS LATER	AMBIENT	9.0×10^{10}	2.7×10^{11}	2.4×10^{11}	1.8×10^{11}

FIGURE VII-6. Insulation Resistance Values Amco No. 8.

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	7.3×10^{10}	6.4×10^{10}	9.5×10^{10}	1.8×10^{11}
INITIAL	65	2.6×10^{7}	7.4×10^{7}	1.3×10^{8}	1.1×10^{9}
1	25	3.5×10^{8}	2.8×10^{9}	1.0×10^{10}	2.7×10^{10}
1	65	4.4×10^{7}	1.3×10^{8}	8.4×10^{7}	8.1×10^{8}
2	25	6.7×10^{8}	5.4×10^{9}	1.0×10^{10}	3.6×10^{10}
2	65	5.8×10^{7}	2.0×10^{8}	1.2×10^{8}	8.2×10^{8}
3	25	7.3×10^{8}	5.6×10^{9}	7.7×10^{9}	3.4×10^{10}
3	65	6.2×10^{7}	2.5×10^{8}	1.1×10^{8}	6.8×10^{8}
4	25	8.7×10^{8}	6.3×10^{9}	7.1×10^{9}	3.7×10^{10}
4	65	6.8×10^{7}	3.4×10^{8}	1.2×10^{8}	6.6×10^{8}
5	25	9.4×10^{8}	4.9×10^{9}	7.1×10^{9}	2.4×10^{10}
5	65	7.4×10^{7}	2.9×10^{8}	1.3×10^{8}	6.0×10^{8}
6	25	1.1×10^{9}	5.2×10^{9}	6.6×10^{9}	2.9×10^{10}
6	65	7.3×10^{7}	2.7×10^{8}	1.1×10^{8}	5.5×10^{8}
7	25	1.3×10^{9}	6.8×10^{9}	7.3×10^{9}	3.4×10^{10}
7	65	8.1×10^{7}	3.7×10^{8}	1.6×10^{8}	5.7×10^{8}
8	25	1.2×10^{9}	6.5×10^{9}	1.2×10^{8}	2.8×10^{10}
8	65	7.2×10^{7}	3.0×10^{8}	1.2×10^{8}	4.8×10^{8}
9	25	1.4×10^{9}	2.8×10^{9}	1.1×10^{10}	3.1×10^{10}
9	65	8.8×10^{7}	3.3×10^{8}	1.7×10^{8}	5.3×10^{8}
10	25	1.4×10^{9}	2.3×10^{9}	1.3×10^{10}	3.3×10^{10}
10	65	7.8×10^{7}	2.5×10^{8}	1.3×10^{8}	4.1×10^{8}
FINAL	AMBIENT	3.0×10^{9}	1.9×10^{11}	7.1×10^{10}	8.2×10^{10}
3 DAYS LATER	AMBIENT	6.3×10^{10}	6.9×10^{10}	7.0×10^{10}	6.0×10^{10}

FIGURE VII-7. Insulation Resistance Values Cobar 210-35.

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	3.2×10^6	3.2×10^6	1.8×10^6	3.1×10^6
INITIAL	65	4.7×10^6	3.9×10^6	6.1×10^6	1.4×10^8
1	25	6.1×10^8	3.3×10^{10}	8.4×10^9	9.4×10^9
1	65	3.0×10^7	1.2×10^9	3.0×10^8	4.5×10^8
2	25	5.9×10^8	5.1×10^{10}	2.2×10^{10}	1.2×10^{10}
2	65	4.0×10^7	1.8×10^9	4.0×10^8	7.3×10^8
3	25	7.0×10^8	6.8×10^{10}	3.1×10^{10}	1.4×10^{10}
3	65	3.0×10^7	1.52×10^9	2.6×10^8	7.0×10^8
4	25	7.0×10^8	7.4×10^{10}	3.3×10^{10}	1.4×10^{10}
4	65	3.5×10^7	1.8×10^9	2.7×10^8	7.3×10^8
5	25	9.5×10^8	1.4×10^{11}	6.1×10^{10}	1.9×10^{10}
5	65	3.1×10^7	3.1×10^9	4.0×10^8	7.8×10^8
6	25	7.3×10^8	7.8×10^{10}	1.6×10^{10}	1.6×10^{10}
6	65	3.0×10^7	1.6×10^9	1.9×10^8	7.3×10^8
7	25	7.8×10^8	8.0×10^{10}	1.3×10^{10}	1.6×10^{10}
7	65	2.6×10^7	1.2×10^9	1.8×10^8	7.0×10^8
8	25	8.0×10^8	2.1×10^{10}	1.15×10^{10}	1.5×10^{10}
8	65	3.8×10^7	1.5×10^9	2.0×10^8	7.0×10^8
9	25	1.3×10^9	1.2×10^{11}	3.5×10^{10}	1.2×10^{10}
9	65	4.7×10^7	1.2×10^9	2.5×10^8	6.6×10^8
10	25	1.5×10^9	1.5×10^{11}	4.2×10^{10}	1.7×10^{10}
10	65	4.1×10^7	1.2×10^9	2.2×10^8	6.1×10^8
FINAL	AMBIENT	6.0×10^9	6.5×10^{11}	4.0×10^{11}	9.0×10^{10}
1 DAY LATER	AMBIENT	3.8×10^{11}	1.2×10^{12}	9.4×10^{11}	9.9×10^{11}

FIGURE VII-8. Insulation Resistance Values Lonco 106-A-35X-MIL.

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	3.7×10^{6}	2.3×10^{7}	2.0×10^{6}	2.8×10^{6}
INITIAL	65	4.7×10^{6}	3.2×10^{8}	6.4×10^{7}	4.9×10^{7}
1	25	6.1×10^{8}	1.8×10^{10}	5.6×10^{9}	1.0×10^{9}
1	65	3.0×10^{7}	7.0×10^{8}	5.7×10^{8}	4.8×10^{7}
2	25	5.9×10^{8}	2.6×10^{10}	5.0×10^{10}	1.6×10^{9}
2	65	4.0×10^{7}	8.6×10^{8}	1.8×10^{9}	7.0×10^{7}
3	25	7.0×10^{8}	3.0×10^{10}	1.3×10^{11}	1.9×10^{9}
3	65	3.0×10^{7}	7.1×10^{8}	1.5×10^{9}	7.0×10^{7}
4	25	7.0×10^{8}	3.3×10^{10}	1.8×10^{11}	2.4×10^{9}
4	65	3.5×10^{7}	5.1×10^{8}	1.52×10^{9}	1.0×10^{8}
5	25	9.5×10^{8}	3.7×10^{10}	2.3×10^{11}	7.4×10^{9}
5	65	3.1×10^{7}	5.0×10^{8}	1.3×10^{9}	9.5×10^{7}
6	25	7.3×10^{8}	2.5×10^{11}	1.4×10^{11}	6.3×10^{8}
6	65	3.0×10^{7}	4.9×10^{8}	1.2×10^{9}	2.1×10^{7}
7	25	7.8×10^{8}	2.5×10^{10}	1.3×10^{11}	6.3×10^{8}
7	65	2.6×10^{7}	4.4×10^{8}	1.0×10^{9}	9.3×10^{7}
8	25	8.0×10^{8}	1.2×10^{10}	1.3×10^{11}	4.2×10^{9}
8	65	3.8×10^{7}	4.2×10^{8}	1.2×10^{9}	1.4×10^{8}
9	25	1.3×10^{9}	9.8×10^{9}	2.0×10^{11}	1.1×10^{10}
9	65	4.7×10^{7}	3.9×10^{8}	1.4×10^{9}	1.5×10^{8}
10	25	1.5×10^{9}	2.0×10^{10}	2.1×10^{11}	3.7×10^{9}
10	65	4.1×10^{7}	3.5×10^{8}	1.1×10^{9}	1.3×10^{8}
FINAL	AMBIENT	6.0×10^{9}	1.6×10^{10}	5.2×10^{10}	2.0×10^{9}
1 DAY LATER	AMBIENT	3.8×10^{11}	6.5×10^{11}	1.1×10^{12}	8.9×10^{11}

FIGURE VII-9. Insulation Resistance Values Kester 1585-MIL.

DAY	TEMP °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	3.7×10^{6}	8.6×10^{5}	1.1×10^{8}	2.2×10^{6}
INITIAL	65	4.7×10^{6}	3.4×10^{8}	5.4×10^{8}	5.1×10^{8}
1	25	6.1×10^{8}	1.5×10^{10}	3.7×10^{10}	2.7×10^{8}
1	65	3.0×10^{7}	6.3×10^{8}	2.2×10^{9}	9.4×10^{7}
2	25	5.9×10^{8}	3.7×10^{10}	7.6×10^{10}	3.3×10^{8}
2	65	4.0×10^{7}	1.3×10^{9}	3.8×10^{9}	9.0×10^{7}
3	25	7.0×10^{8}	5.7×10^{10}	1.0×10^{11}	7.3×10^{8}
3	65	3.0×10^{7}	1.2×10^{9}	5.0×10^{9}	1.1×10^{8}
4	25	7.0×10^{8}	7.4×10^{10}	1.0×10^{11}	8.0×10^{8}
4	65	3.5×10^{7}	1.2×10^{9}	4.4×10^{9}	1.0×10^{8}
5	25	9.5×10^{8}	1.5×10^{11}	1.3×10^{11}	1.3×10^{9}
5	65	3.1×10^{7}	1.3×10^{9}	4.0×10^{9}	1.1×10^{8}
6	25	7.3×10^{8}	6.4×10^{10}	7.7×10^{10}	1.0×10^{9}
6	65	3.0×10^{7}	1.4×10^{9}	3.6×10^{9}	1.9×10^{8}
7	25	7.8×10^{8}	6.5×10^{10}	7.0×10^{10}	1.1×10^{9}
7	65	2.6×10^{7}	1.0×10^{9}	3.2×10^{9}	1.2×10^{8}
8	25	8.0×10^{8}	7.1×10^{10}	5.4×10^{10}	1.2×10^{9}
8	65	3.8×10^{7}	1.2×10^{9}	3.3×10^{9}	1.3×10^{8}
9	25	1.3×10^{9}	1.0×10^{11}	8.0×10^{10}	2.0×10^{9}
9	65	4.7×10^{7}	1.5×10^{9}	3.2×10^{9}	1.3×10^{8}
10	25	1.5×10^{9}	1.2×10^{11}	9.7×10^{10}	2.5×10^{9}
10	65	4.1×10^{7}	1.4×10^{9}	3.2×10^{9}	1.1×10^{8}
FINAL	AMBIENT	6.0×10^{9}	5.1×10^{10}	3.8×10^{10}	1.5×10^{9}
1 DAY LATER	AMBIENT	3.8×10^{11}	1.5×10^{12}	8.8×10^{11}	6.4×10^{11}

FIGURE VII-10. Insulation Resistance Values Kenco 465-MIL.

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	2.0×10^{9}	2.5×10^{7}	2.6×10^{7}	2.7×10^{8}
INITIAL	65	4.2×10^{8}	8.2×10^{5}	1.9×10^{7}	3.8×10^{6}
1	25	8.9×10^{9}	2.3×10^{7}	1.8×10^{9}	1.6×10^{7}
1	65	9.1×10^{8}	2.8×10^{6}	4.8×10^{7}	4.5×10^{6}
2	25	2.5×10^{10}	8.5×10^{7}	2.4×10^{9}	7.8×10^{7}
2	65	6.3×10^{8}	6.2×10^{6}	7.4×10^{7}	7.7×10^{6}
3	25	1.8×10^{10}	1.1×10^{8}	3.5×10^{9}	2.5×10^{8}
3	65	6.8×10^{8}	1.0×10^{7}	9.8×10^{7}	1.1×10^{7}
4	25	1.5×10^{10}	1.2×10^{8}	3.4×10^{9}	3.4×10^{8}
4	65	4.6×10^{8}	1.2×10^{7}	1.1×10^{8}	1.3×10^{7}
5	25	1.7×10^{10}	1.4×10^{8}	5.4×10^{9}	8.2×10^{8}
5	65	6.0×10^{8}	1.7×10^{7}	1.4×10^{8}	1.6×10^{7}
6	25	1.6×10^{10}	1.7×10^{8}	6.2×10^{9}	9.5×10^{8}
6	65	5.3×10^{8}	1.8×10^{7}	1.5×10^{8}	1.9×10^{7}
7	25	1.6×10^{10}	1.8×10^{8}	7.3×10^{9}	7.1×10^{9}
7	65	5.0×10^{8}	1.8×10^{7}	1.5×10^{8}	1.9×10^{7}
8	25	2.3×10^{10}	2.2×10^{8}	9.9×10^{9}	1.7×10^{9}
8	65	5.7×10^{8}	2.4×10^{7}	2.0×10^{8}	2.6×10^{7}
9	25	2.8×10^{10}	2.5×10^{8}	1.2×10^{10}	2.3×10^{9}
9	65	8.4×10^{8}	2.2×10^{7}	2.1×10^{8}	2.6×10^{7}
10	25	2.0×10^{10}	1.8×10^{8}	8.1×10^{9}	1.4×10^{9}
10	65	6.8×10^{8}	2.3×10^{7}	2.2×10^{8}	2.6×10^{7}
FINAL	AMBIENT	4.3×10^{11}	1.0×10^{11}	3.2×10^{11}	1.0×10^{11}
1 DAY LATER	AMBIENT	3.3×10^{11}	9.6×10^{10}	2.4×10^{11}	1.1×10^{11}

FIGURE VII-11. Insulation Resistance Values Kenco 192.

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	2.0×10^{9}	2.4×10^{8}	2.1×10^{8}	9.8×10^{7}
INITIAL	65	4.2×10^{8}	2.5×10^{7}	4.5×10^{7}	1.6×10^{7}
1	25	8.9×10^{9}	2.6×10^{8}	6.7×10^{8}	2.1×10^{8}
1	65	9.1×10^{8}	5.4×10^{7}	6.9×10^{7}	2.3×10^{7}
2	25	2.5×10^{10}	3.7×10^{8}	8.9×10^{8}	2.6×10^{8}
2	65	6.3×10^{8}	6.7×10^{7}	9.0×10^{7}	2.9×10^{7}
3	25	1.8×10^{10}	4.4×10^{8}	1.1×10^{9}	2.5×10^{8}
3	65	6.8×10^{8}	7.5×10^{7}	1.1×10^{8}	3.1×10^{7}
4	25	1.5×10^{11}	4.9×10^{8}	1.1×10^{9}	2.8×10^{8}
4	65	4.6×10^{8}	8.2×10^{7}	9.3×10^{7}	3.3×10^{7}
5	25	1.7×10^{10}	8.1×10^{8}	7.4×10^{8}	4.3×10^{8}
5	65	6.0×10^{8}	1.13×10^{8}	1.2×10^{8}	4.0×10^{7}
6	25	1.6×10^{10}	1.0×10^{9}	1.4×10^{9}	4.5×10^{8}
6	65	5.3×10^{8}	1.1×10^{8}	8.8×10^{7}	4.0×10^{7}
7	25	1.6×10^{10}	1.3×10^{9}	1.4×10^{9}	4.6×10^{8}
7	65	5.0×10^{8}	1.1×10^{8}	8.0×10^{7}	4.3×10^{7}
8	25	2.3×10^{10}	2.0×10^{9}	1.7×10^{9}	6.3×10^{8}
8	65	5.7×10^{8}	1.3×10^{8}	1.2×10^{8}	4.9×10^{7}
9	25	2.8×10^{10}	2.2×10^{9}	1.8×10^{9}	6.4×10^{8}
9	65	8.4×10^{8}	1.3×10^{8}	8.7×10^{7}	4.7×10^{7}
10	25	2.0×10^{10}	1.9×10^{9}	1.5×10^{9}	4.5×10^{8}
10	65	6.8×10^{8}	1.3×10^{8}	7.9×10^{7}	5.1×10^{7}
FINAL	AMBIENT	4.3×10^{11}	8.7×10^{10}	5.6×10^{10}	6.2×10^{10}
1 DAY LATER	AMBIENT	3.3×10^{11}	4.6×10^{10}	3.3×10^{10}	3.4×10^{10}

FIGURE VII-12. Insulation Resistance Values Amco 220-35.

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	7.3×10^{10}	2.3×10^{9}	1.9×10^{8}	5.7×10^{8}
INITIAL	65	2.6×10^{7}	2.5×10^{5}	1.1×10^{4}	2.2×10^{5}
1	25	3.5×10^{8}	1.5×10^{6}	4.5×10^{5}	1.7×10^{6}
1	65	4.4×10^{7}	4.4×10^{4}	1.4×10^{5}	2.0×10^{5}
2	25	6.7×10^{8}	2.6×10^{6}	7.6×10^{4}	1.9×10^{6}
2	65	5.8×10^{7}	6.4×10^{4}	1.7×10^{4}	2.3×10^{4}
3	25	7.3×10^{8}	3.0×10^{6}	8.4×10^{4}	1.3×10^{6}
3	65	6.2×10^{7}	5.9×10^{4}	1.5×10^{4}	2.0×10^{4}
4	25	8.7×10^{8}	2.5×10^{6}	8.3×10^{4}	1.1×10^{6}
4	65	6.8×10^{7}	5.3×10^{5}	1.6×10^{5}	2.4×10^{5}
5	25	9.4×10^{8}	3.0×10^{6}	1.2×10^{6}	1.4×10^{6}
5	65	7.4×10^{7}	4.7×10^{5}	1.8×10^{5}	2.9×10^{5}
6	25	1.1×10^{9}	3.5×10^{6}	1.2×10^{6}	1.5×10^{6}
6	65	7.3×10^{7}	1.1×10^{4}	2.1×10^{5}	2.9×10^{5}
7	25	1.3×10^{9}	1.0×10^{4}	1.6×10^{6}	1.3×10^{6}
7	65	8.1×10^{7}	6.4×10^{5}	2.2×10^{5}	4.1×10^{5}
8	25	1.2×10^{9}	2.0×10^{6}	1.6×10^{6}	2.2×10^{6}
8	65	7.2×10^{7}	1.2×10^{4}	1.9×10^{5}	2.8×10^{5}
9	25	1.4×10^{9}	1.0×10^{5}	1.9×10^{6}	9.3×10^{3}
9	65	8.8×10^{7}	1.1×10^{5}	2.6×10^{6}	1.3×10^{4}
10	25	1.4×10^{9}	1.2×10^{4}	2.0×10^{6}	9.1×10^{5}
10	65	7.8×10^{7}	1.3×10^{4}	2.3×10^{5}	3.3×10^{5}
FINAL	AMBIENT	3.0×10^{9}	3.0×10^{6}	2.0×10^{6}	4.0×10^{6}
3 DAYS LATER	AMBIENT	6.3×10^{10}	1.3×10^{7}	6.3×10^{6}	8.3×10^{6}

FIGURE VII-13. Insulation Resistance Values Gardiner 5425.

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	2.0×10^{9}	5.6×10^{11}	9.2×10^{9}	8.6×10^{10}
INITIAL	65	4.2×10^{8}	3.5×10^{7}	1.3×10^{7}	4.9×10^{7}
1	25	8.9×10^{9}	7.6×10^{9}	$1.2 \; . \; 10^{9}$	7.5×10^{9}
1	65	9.1×10^{8}	1.2×10^{8}	8.8×10^{7}	1.1×10^{8}
2	25	2.5×10^{10}	1.8×10^{9}	3.5×10^{9}	9.9×10^{9}
2	65	6.3×10^{8}	1.4×10^{8}	1.3×10^{8}	1.6×10^{8}
3	25	1.8×10^{10}	1.2×10^{10}	3.0×10^{9}	1.1×10^{10}
3	65	6.8×10^{8}	1.4×10^{8}	2.0×10^{8}	2.0×10^{8}
4	25	1.5×10^{10}	2.3×10^{10}	2.4×10^{9}	1.2×10^{10}
4	65	4.6×10^{8}	1.4×10^{8}	1.5×10^{8}	2.0×10^{8}
5	25	1.7×10^{10}	3.2×10^{10}	3.0×10^{9}	1.7×10^{10}
5	65	6.0×10^{8}	2.2×10^{8}	2.4×10^{8}	2.4×10^{8}
6	25	1.6×10^{10}	4.0×10^{10}	2.9×10^{9}	1.7×10^{10}
6	65	5.3×10^{8}	1.6×10^{8}	2.6×10^{8}	2.3×10^{8}
7	25	1.6×10^{10}	4.6×10^{10}	2.9×10^{9}	1.9×10^{10}
7	65	5.0×10^{8}	1.4×10^{8}	2.1×10^{8}	2.1×10^{8}
8	25	2.3×10^{10}	4.7×10^{10}	3.9×10^{9}	2.1×10^{10}
8	65	5.7×10^{8}	1.6×10^{8}	3.6×10^{8}	2.7×10^{8}
9	25	2.8×10^{10}	6.7×10^{10}	4.1×10^{9}	2.2×10^{10}
9	65	8.4×10^{8}	1.5×10^{8}	3.4×10^{8}	2.4×10^{8}
10	25	2.0×10^{10}	3.5×10^{10}	2.9×10^{9}	1.7×10^{10}
10	65	6.8×10^{8}	1.4×10^{8}	2.8×10^{8}	2.4×10^{8}
FINAL	AMBIENT	4.3×10^{11}	3.7×10^{11}	3.4×10^{11}	1.4×10^{11}
1 DAY LATER	AMBIENT	3.3×10^{11}	3.1×10^{11}	1.8×10^{11}	1.8×10^{11}

FIGURE VII-14. Insulation Resistance Values Lonco 3355-11.

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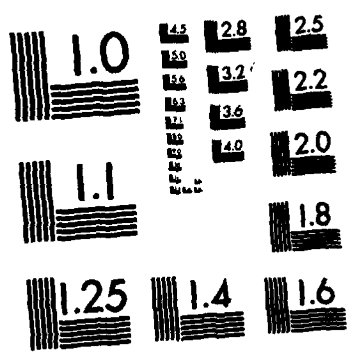


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	7.3×10^{10}	2.0×10^{10}	6.5×10^{10}	7.1×10^{10}
INITIAL	65	2.6×10^{7}	9.1×10^{5}	6.2×10^{6}	5.1×10^{6}
1	25	3.5×10^{8}	3.6×10^{7}	2.1×10^{8}	2.7×10^{8}
1	65	4.4×10^{7}	3.0×10^{6}	1.2×10^{7}	1.3×10^{7}
2	25	6.7×10^{8}	8.7×10^{7}	4.6×10^{8}	5.4×10^{8}
2	65	5.8×10^{7}	5.2×10^{6}	1.7×10^{7}	2.1×10^{7}
3	25	7.3×10^{8}	1.2×10^{8}	6.2×10^{8}	6.1×10^{8}
3	65	6.2×10^{7}	7.1×10^{6}	2.3×10^{7}	2.5×10^{7}
4	25	8.7×10^{8}	1.8×10^{8}	8.8×10^{8}	7.5×10^{8}
4	65	6.8×10^{7}	9.1×10^{6}	2.3×10^{7}	2.2×10^{7}
5	25	9.4×10^{8}	2.1×10^{8}	1.2×10^{9}	1.0×10^{9}
5	65	7.4×10^{7}	1.1×10^{7}	3.0×10^{7}	3.5×10^{7}
6	25	1.1×10^{9}	2.6×10^{8}	2.0×10^{9}	1.3×10^{9}
6	65	7.3×10^{7}	1.1×10^{7}	3.1×10^{7}	3.6×10^{7}
7	25	1.3×10^{9}	3.2×10^{8}	3.7×10^{9}	1.8×10^{9}
7	65	8.1×10^{7}	1.5×10^{7}	3.9×10^{7}	4.7×10^{7}
8	25	1.2×10^{9}	3.4×10^{8}	4.7×10^{9}	1.9×10^{9}
8	65	7.2×10^{7}	1.6×10^{7}	4.0×10^{7}	4.9×10^{7}
9	25	1.4×10^{9}	3.7×10^{8}	7.1×10^{9}	2.3×10^{9}
9	65	8.8×10^{7}	2.0×10^{7}	5.0×10^{7}	5.7×10^{7}
10	25	1.4×10^{9}	3.8×10^{8}	9.0×10^{9}	2.5×10^{9}
10	65	7.8×10^{7}	2.0×10^{7}	5.1×10^{7}	5.7×10^{7}
FINAL	AMBIENT	3.0×10^{9}	5.0×10^{8}	8.6×10^{8}	4.4×10^{8}
3 DAYS LATER	AMBIENT	6.3×10^{10}	3.3×10^{10}	6.7×10^{10}	6.9×10^{10}

FIGURE VII-15. Insulation Resistance Values Kester 2331.

DAY	TEMP, °C	STANDARD (OHMS)	SAMPLE A (OHMS)	SAMPLE B (OHMS)	SAMPLE C (OHMS)
INITIAL	AMBIENT	1.4×10^{11}	1.1×10^{11}	8.3×10^{10}	8.3×10^{10}
INITIAL	65	4.8×10^{7}	5.5×10^{6}	8.2×10^{6}	4.9×10^{6}
1	25	3.9×10^{9}	1.1×10^{9}	1.9×10^{9}	4.0×10^{8}
1	65	4.3×10^{7}	6.6×10^{6}	1.2×10^{7}	7.9×10^{6}
2	25	4.4×10^{9}	1.3×10^{9}	2.6×10^{9}	7.2×10^{8}
2	65	5.7×10^{7}	1.1×10^{7}	1.5×10^{7}	1.1×10^{7}
3	25	5.4×10^{9}	1.2×10^{9}	3.5×10^{9}	1.0×10^{9}
3	65	7.1×10^{7}	1.4×10^{7}	1.7×10^{7}	1.1×10^{7}
4	25	8.4×10^{9}	2.2×10^{9}	6.7×10^{9}	1.2×10^{9}
4	65	6.7×10^{7}	1.6×10^{7}	2.0×10^{7}	1.3×10^{7}
5	25	6.3×10^{9}	1.5×10^{9}	4.3×10^{9}	1.1×10^{9}
5	65	7.8×10^{7}	2.4×10^{7}	2.7×10^{7}	1.2×10^{7}
6	25	5.9×10^{9}	1.6×10^{9}	4.6×10^{9}	8.9×10^{8}
6	65	8.6×10^{7}	2.1×10^{7}	2.5×10^{7}	1.3×10^{7}
7	25	6.4×10^{9}	1.9×10^{9}	4.1×10^{9}	8.7×10^{8}
7	65	9.8×10^{7}	2.5×10^{7}	3.4×10^{7}	1.5×10^{7}
8	25	6.5×10^{9}	1.8×10^{9}	4.2×10^{9}	8.3×10^{8}
8	65	8.0×10^{7}	2.3×10^{7}	2.8×10^{7}	1.5×10^{7}
9	25	4.8×10^{9}	1.3×10^{9}	2.4×10^{9}	6.0×10^{8}
9	65	1.0×10^{8}	2.5×10^{7}	3.1×10^{7}	1.3×10^{7}
10	25°C	8.0×10^{9}	2.1×10^{9}	4.4×10^{9}	8.0×10^{8}
10	65°C	7.2×10^{7}	2.4×10^{7}	1.6×10^{7}	1.0×10^{7}
FINAL	AMBIENT	8.3×10^{8}	7.7×10^{8}	1.8×10^{8}	7.2×10^{8}

FIGURE VII-16. Insulation Resistance Values Kenco 183.

VIII. CONCLUSION

As the solvent testing shows, it is possible to clean both the RMA and the RA fluxes to an acceptable level of ionic cleanliness when using the proper solvent. The best solvents were the bi-polar solvent mixtures containing a large percentage of alcohol.

Aqueous testing demonstrates that cleaning using water alone, whether tap water or deionized water, will not clean the flux from the board to an acceptable level. Use of the proper detergent and its correct concentration can remove ionic contamination from most RMA fluxed boards and from several of the non-rosin fluxed boards. No RA fluxes were cleaned with a detergent to an acceptable ionic cleanliness level.

The broad category of non-rosin fluxes behaved in markedly different ways to each test. Some non-rosin fluxes were ionically removed very well, while others could not be cleaned in any of the processes.

The solderability comparison of all the fluxes types showed that overall non-rosin fluxes soldered the best because they had the highest force readings. The RMA and RA fluxes gave lower force readings but neither group was significantly better than the other.

The combination cleaning process using a solvent degreasing followed by a deionized water rinse proved to be a very effective method of removing ionic contamination from rosin fluxed samples. Non-rosin fluxes did not show as clean results.

Insulation resistance testing shows that the RMA fluxes have no degrading effects upon the boards. The same is true for the RA fluxes.

The non-rosin fluxes, however, lowered the resistance of the board even though they had passed ionic cleanliness testing.

Neither the ionic cleanliness test nor the insulation resistance test, by itself, is an adequate method for determining the entire effect that a flux has upon the printed wiring board. No test has yet been developed for detecting both ionic and non-ionic contamination. This test method must be suited to production line use. It must be easy, quick and use safe chemicals. Until this more complete method is developed neither ionic testing or insulation resistance testing can be used alone to evaluate a flux.

Using the ionic test in conjunction with the resistance test it is possible to get an indication of the effect from a flux. The RMA fluxes, the type of fluxes with a history of reliability, passed both the ionic and the resistance tests. The RA fluxes failed ionic testing and passed resistance testing, probably due to the insulation effect of rosin. Some of the non-rosin fluxes passed ionic testing yet degraded the resistance characteristics of the board.

It is recommended that non-rosin fluxes not be used on military hardware because of their devastating effects on the resistance characteristics of the board.

To emphasize the significant findings of the study:

- Non-rosin fluxes degrade the resistance characteristics of the printed circuit board--these fluxes should not be used on military and other critical hardware.

- Water alone cannot adequately remove flux.

- The working life of a detergent must be closely monitored in order to ensure removal of flux.

- RA fluxes cannot be cleaned to an acceptable level by detergent cleaning.

- The best cleaning methods for rosin fluxes are:

  - Vapor degreasing using solvents containing a high percentage of alcohol.

  - Combination cleaning using vapor degreasing followed by deionized water rinse.

Solvent Cleaning in Vapor Degreaser	→	Deionized Water Rinse
• Solvent containing a high percentage of alcohol		• 2 megohm-cm or greater dionized water

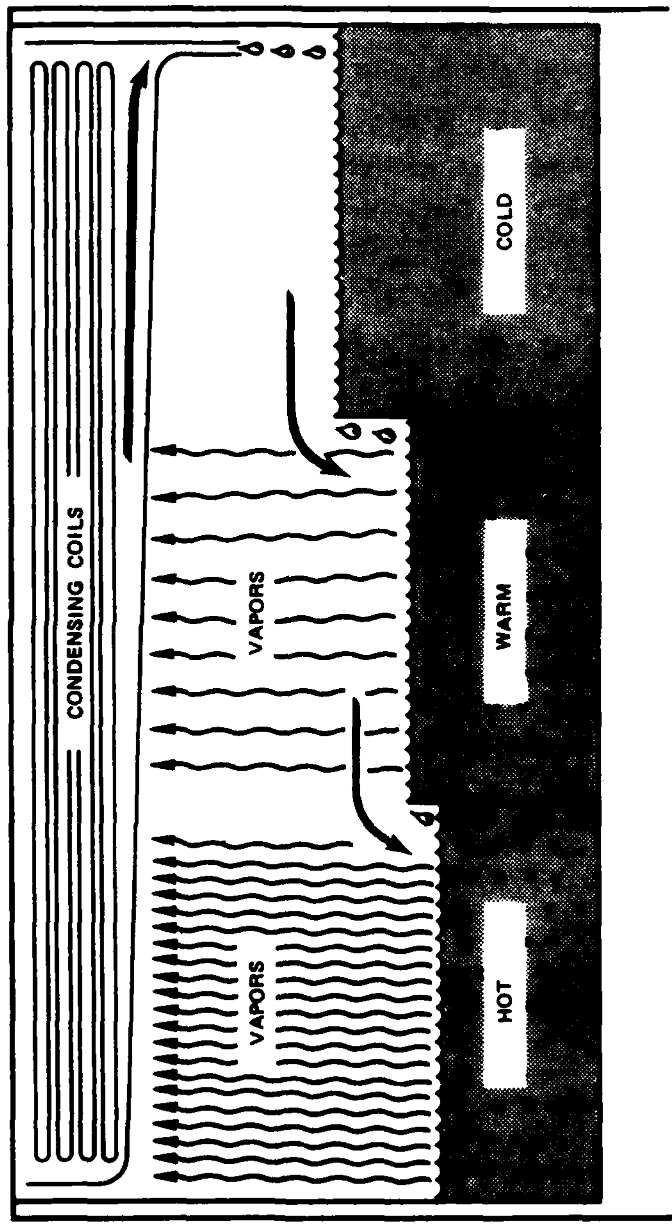
- Neither ionic cleanliness nor insulation resistance testing, by itself, can determine the effect a flux has on a circuit board.

Appendix A

VAPOR DEGREASER

The vapor degreaser used in this study is a Unique Industries VaporKleen Model 500. An autoarm attached to the vapor degreaser was used to control the time in each tank. A schematic of the degreaser is shown in Figure A-1. The cleaning cycles that were used in this study were 2-1-1 and 4-2-2. The first value is the number of minutes that the samples were submerged in the boiling solvent; the second value is the number of minutes that the samples were submerged in the warm solvent; and the third value is the number of minutes the samples were suspended in the vapors above the boiling solvent.

All pre-cleaning of sample boards was accomplished with Freon TE. When other solvents were tested, the degreaser was drained of Freon TE, cleaned, purged with fresh test solvent, drained again, and then filled with the test solvent. The specific gravity and the temperature of the test solvent was recorded for each of the three tanks. Color change of the solvent was used as a rough indication of the need for fresh solvent.



A–1. THREE–STAGE VAPOR DEGREASER.

Appendix B

AQUEOUS CLEANER

The aqueous cleaning unit that was used in this study is a five-stage system from the John Treiber Company (see Figure B-1). Fresh water enters the system in the final rinse stage allowing the purest water to rinse the board last. The final rinse then cascades to the rinse stage and from there cascades to the pre-rinse stage and then to the drain. For all tests, the wash stage was heated to 140°F.

Neoprene rubber curtains separate each stage. Two sets of curtains surround each side of the wash stage to prevent drag through of detergent. The pre-rinse stage is 18 inches long and contains four small nozzles, two spray from the top and two spray from the bottom. The wash tank is 40 inches long, containing eight large nozzles that spray from the top and eight small nozzles that spray from the bottom. The rinse tank contains two large nozzles that spray from the top and four small nozzles that spray from the bottom. The length of the rinse tank is 18 inches. The final rinse tank, also 18 inches long, contains four small nozzles that spray from the top and four small nozzles that spray from the bottom.

The dry stage is 60 inches long and contains air knives, top and bottom, a set of infrared heating elements, and another set of top and bottom air knives.

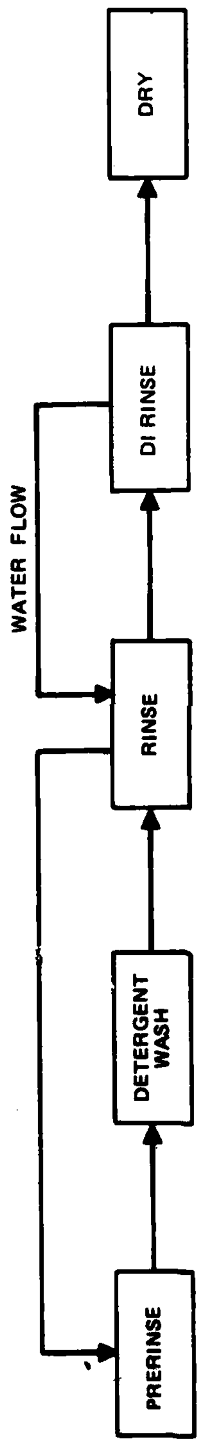
A small nozzle delivers 0.64 gallons and a large nozzle delivers 1.27 gallons during the length of the wash stage. Each test board was washed with approximately two gallons of water--the equivalent of one small and one large nozzle.

The conveyor speed of the aqueous cleaner was set at 55, which equates to a speed of 5.3 feet per minute.

All deionized water was generated at the test facility. A two-stage system was used to purify tap water. The first stage consists of a cation exchange column and an anion exchange column. The use of this stage alone produces 2 x 10^5 ohm-cm water. The second stage of the system is a mixed bed deionizing column. The combination of the two stages produce 18 megohm-cm water.

The tap water testing was performed in the Fall of 1980. Analysis of the tap water that is supplied to the facility is taken periodically and was tested in November of 1980. The results are given in three ways: total dissolved solids, hardness, and concentration of commonly found contaminants. The total dissolved solids were 320 ppm; the hardness was 90 ppm, or 5.2 grains per gallon. A value less than 100 ppm, or 5.8 grains per gallon, is generally considered to be soft water. Concentrations for other contaminants are listed below.

Ca	11.0 ppm
Na	61.0 ppm
Cl^-	29.0 ppm
F^-	0.93 ppm
$SO_4^=$	19.0 ppm



B–1. AQUEOUS CLEANER.

Appendix C

CLEANLINESS TESTER

Several parameters had to be set before the use of the Ionograph could be standardized. The selection of an appropriate solvent system was based on raw flux ionic contamination tests which showed that a 75% isopropanol/25% deionized water solvent system detected more ionic contamination than a 50% isopropanol/50% deionized water solvent system (see Figure C-1). A saturation test was also conducted on the RA and the RMA fluxes. Figure C-2 shows how different solvent systems affect the saturation of fluxes. The number in each column is the number of drops of flux that can dissolve in each solution before reaching the saturation point. The table shows that the 75% isopropanol/25% deionized water solvent system dissolved much more flux than either the 65% isopropanol/35% deionized water solvent system or the 50% isopropanol/50% deionized water solvent system.

The null point was set at a level that was greater than the required reference purity level of 20 megohm-cm specified in WS-6536D (paragraph 3.6.5.2). The selected null point was 0.02 micromhos per centimeter or 50 megohm-cm.

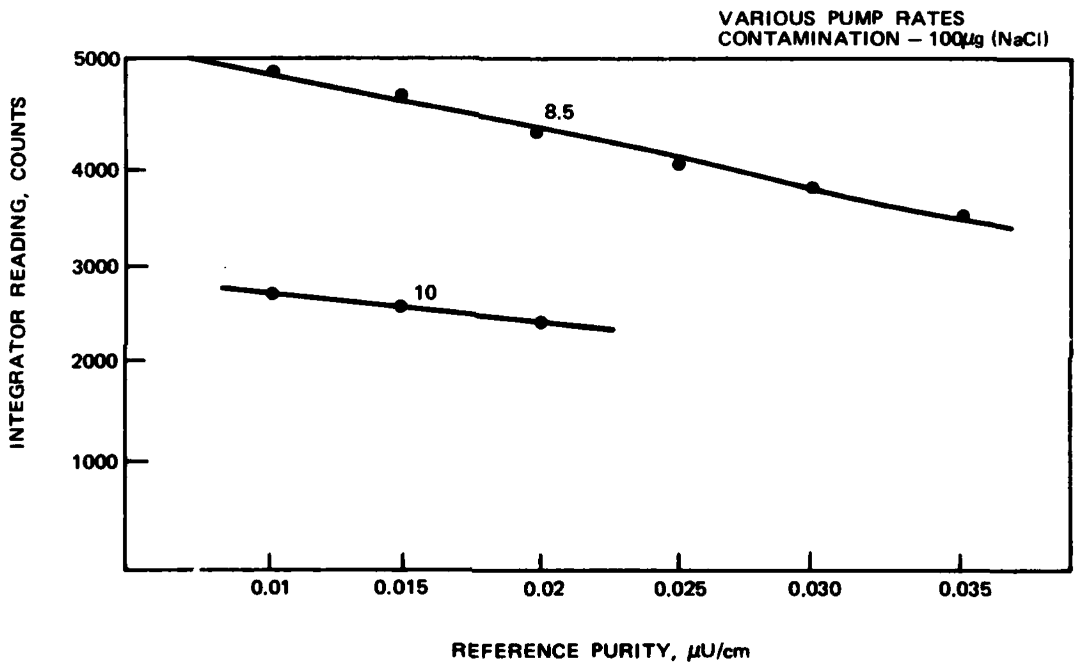
The next parameter that needed to be set was pump rate. The pump rate has an effect on the sensitivity of the cleanliness test. The faster the pump rate, the less sensitive the test. Figure C-3 shows that an injection of 100 microliters of sodium chloride at a null point of 0.02 micromhos/cm, a pump rate of 8.5 detects more ionic contamination than a pump rate of 10. It is for this reason that the 8.5 pump rate was selected.

FLUX	50/50	75/25
FRY 600	7.58	8.95
KESTER 2300	12.3	19.2
KESTER 2154	10.3	16.5
KESTER 2330	10.1	17.4
KENCO 183	12.3	15.2
LONCO 3355-11	11.8	18.1
LONCO 35-WS	7.3	9.3
ALPHA 709	9.8	13.6
ALPHA 850-33	9.63	11.7
COBAR 353	5.26	11.9
GARDINER 5425	7.30	10.4
GARDINER 5830	11.9	17.7
KESTER 2331	8.06	14.9
KENCO 192	11.1	17.8
AMCO 220-35	8.09	13.7

FIGURE C-1. Raw Flux Injection (μg/μl).

FLUX	75/25	65/35	50/50
RMA			
ALPHA 611F	900 DROPS	400 DROPS	65 DROPS
KESTER 197	900	400	25
COBAR 210-35	900	400	65
RA			
LONCO 106-A-35X-MIL	900	65	9
ALPHA 711	900	400	12
KENCO 413	900	400	25
KESTER 1585	900	400	25

FIGURE C-2. Flux Saturation Tests.



C-3. PUMP RATE EFFECT

Appendix D

NOTICE TO FLUX MANUFACTURERS

Additional written requests for further tests of significantly different fluxes will be considered. Discussion of test procedures will be completed with both military and flux manufacturer representatives. Feedback on the findings in this study is welcome.

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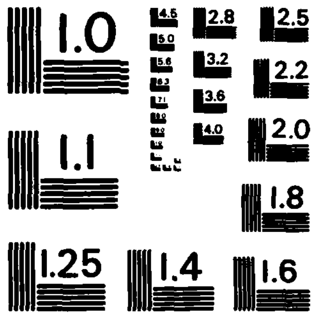

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SUPPLEMENTARY

INFORMATION

Errata

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14 Oct 83